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MARVELS IN WORLD OF LIGHT

DEAN OVENDEN.

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MARVELS IN THE WORLD OF LIGHT

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MARVELS IN THE WORLD OF LIGHT

A POPULAR STUDY OF THE PHENOMENA OF LIGHT, COLOUR AND SIGHT

BY THE

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04187
11/4/05

PUBLISHED UNDER THE DIRECTION OF THE GENERAL LITERATURE COMMITTEE

LONDON:
SOCIETY FOR PROMOTING CHRISTIAN KNOWLEDGE,
NORTHUMBERLAND AVENUE, W.C.; 43, QUEEN VICTORIA STREET, E.C.
BRIGHTON: 129, NORTH STREET.
NEW YORK: E. S. GORHAM.

1904

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INTRODUCTION

In this book an attempt has been made to present to lovers of Nature an account of the phenomena of Light in simple language which every one can understand, so that they may grasp the wonders of those laws by which it is governed, and get some idea of the infinite wisdom which designed and selected light as the great foundation-stone of all organic life.

Without light there could be no trees, no grass, nor any green plant, and, therefore, no food for man or beast.

Light is such a common thing that many fail to realize the great interest and pleasure which may be found in the study of its nature, its laws and its operation.

Closely connected with light is the organ, the eye, by which we are enabled to perceive its existence.

The examination of colour and sight reveals a marvellous and intricate arrangement by which light and the eye were made mutually responsive so as to render sight possible.

Many of these most interesting facts are unknown to thousands, who have no idea of the nature of light, colour and sight.

To bring this knowledge within the reach of ordinary unscientific people, this book has been arranged either for private study, or for readings, illustrated by a magic lantern, which may be delivered by a clergyman or layman in a parochial hall, to an ordinary mixed audience.

An evening spent in the consideration of such a subject would leave more permanent result behind than the usual winter entertainment of readings, recitations and songs.

Scientific subjects are deeply interesting if they can be taught in a popular way, so as to be clearly understood.

Each portion of the book is written so as to be a suitable length for an evening entertainment, and directions are given in the appendix by which any person can convert the illustrations (drawn in outline by the author) into slides for a magic lantern.

MARVELS IN THE WORLD OF LIGHT

I

LIGHT AND ITS LAWS

If we want proof of the unity of all nature, we can find strong evidence of the fact in the study of light and its laws. Man's mind is incapable of forming any definite idea of the size of space. If we stood on a hill and surveyed a vast plain, we might feel that the landscape spread out before us might be called space, yet all we could see could be represented by a small spot on an ordinary map. When we gaze on Venus, the evening star, we see in that speck of light a world very nearly as large as our own, but it lies at a vast distance from us; yet when compared with the distance of the fixed stars, it is quite close. Light travels at the enormous velocity of about 186,000 miles in a second, but the evening star is so distant that its light takes about seven or eight minutes to reach us, according to the part of its orbit it may be in.

A ray of light starting from a fixed star may take

some centuries to reach us, although every second of that time it has been rushing towards us at that amazing speed. But there are millions of stars so distant that they have never been seen by man. The light shining from them, though so faint that it cannot be seen, has been, nevertheless, recorded on a sensitive photographic plate attached to a telescope and exposed for some hours on a clear night. We may abandon the effort to conceive the distance of these stars, but the light which shines from them is regulated by the very same laws which govern the light shining from a lamp on a table in a cottage. Whatever power imposed laws on our home lights imposed the same on every light-giving substance in the entire universe. Surely this fact must make our present study of light intensely interesting. We know that light is the most beautiful and wonderful phenomenon in the whole creation. Without light there could be no such thing as beauty, and no such sensation as sight.

Light-giving objects may be divided into two classes, those which illuminate—that is, which give out light, like a flame—and those which are illuminated, or reflect light cast upon them by some illuminating substance. We will consider the former class first.

Every substance when sufficiently heated gives out light, but the substance on which we chiefly depend for artificial light is carbon. It is found in various combinations. We know it as lamp-black and soot. In this form it seems devoid of light and

as black as ink. But it is also present in large quantities in transparent coal-gas and in petroleum oil, which may seem as clear as pure water. It is also present in fat, and in the tallow or wax of which a candle is made.

It is easy to discover its presence in these things. When partly burnt they emit a dense black smoke. If a piece of cold iron be introduced into the smoke

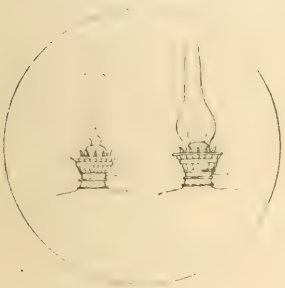

FIG. 1.

FIG. 2.

or the flame, at once it becomes covered with lamp-black.

Smoke is simply carbon escaping unburnt into the air, and it contains little heat, but if a sufficient supply of the oxygen of the air be given, as when we blow up a fire, at once the smoke is converted into light-giving flame, because the particles of carbon are then heated to incandescence.

Every one who lights an oil lamp knows this fact by experience. When the match is applied the lamp smokes, but when the glass chimney is put on,

oxygen flows up through the burner, and the flame becomes clear. Then the particles of carbon are floating in the flame heated white-hot (Fig. 1).

To produce the best light a certain amount of air must be given sufficient to heat the carbon ; but if too much air be supplied, the carbon is not only heated but consumed, and then the flame turns blue, giving out less light, but far more heat.

For this reason gas used for cooking or heating purposes is passed through what is called a Bunsen burner, in which copious air is admitted to mix with the gas by holes in the conducting tubes (Fig. 2).

If a piece of cold iron be held in the flame of a Bunsen burner, no carbon is deposited on it, showing that it has been totally consumed in the blue flame.

To discuss the various methods of producing light by electricity would take us too far from the subject of light itself. Let it suffice to say that electric light is caused by the fact that carbon or other substances can be made white-hot by an electric current.

All artificial lights are but imitations of the great light-giver, the sun. In fact, the light which shines from burning wood or coal is really released sunlight, which has been stored up in these materials. Without sunshine no woody plants could grow. Day by day the sun shone upon them and enabled them to store up carbon by decomposing carbonic acid in the air, and when we burn them either as solids or in gas, we find the carbon in the flame which they develop.

What, then, is daylight ? It is the giving out of

light from billions of particles of carbon and other substances which are heated to such an extent that they float as white-hot vapour on the top of the sun's atmosphere like fleecy clouds of excessive brilliancy.

The nearest approach which man can make towards the manufacture of sunlight is in the dazzling heat and light of an electric furnace.

The sun is placed about 92,000,000 of miles away from us. How, then, does its light reach us? It was a long time before the wisest men were able to answer that question.

Descartes, a famous philosopher, thought that light was transmitted through space instantaneously. He used as an illustration the idea of a blind man walking with a stick in his hand. Whenever he struck anything with the end of the stick he felt the shock instantaneously in his hand. He held that light was a brisk motion in the luminous body, which by means of the air and other transparent media was conveyed to the eye as the shock at the end of the stick was transferred to the hand.

Another scientist, Rœmer, however, made a discovery which upset this theory. He was looking at one of Jupiter's moons (the one nearest the planet), when it passed into its shadow and ceased to shine; soon it emerged from the shadow and shone again. Rœmer noted the exact time. When he made the observation the earth happened to be between the sun and Jupiter (Fig. 3).

Six months later, when the sun was nearly between Jupiter and the earth, he made a similar

observation, but saw, to his amazement, that the eclipse of Jupiter's moon was 15 minutes late. He knew that he was now much further from Jupiter than he had been six months before. "Perhaps," he argued, "the light has taken 15 minutes to cross the orbit of the earth round the sun." He waited until the earth was again approaching the planet, and found that the eclipse was making up for lost time, and that it was right to the minute when the

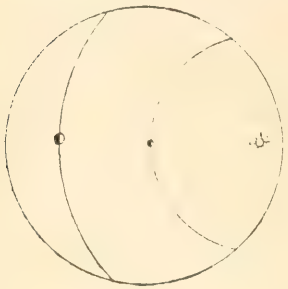

FIG. 3.

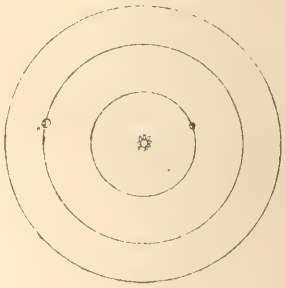

FIG. 4.

earth got back to her former relative position (Fig. 4). He knew the distance of the earth from the sun. That was the radius of the circle. Twice that was the diameter, therefore light had taken 15 minutes to travel across this space.

Subsequent accurate observation of the exact distance of the earth from the sun fixed the rate at which light travels to be 186,000 miles in each second.

Newton explained the transmission of light by the law of the motion of elastic bodies, such as ivory balls on a billiard-table. If the ball strike the

cushion at an angle of 45 degrees it rebounds from it at the same angle, just as a ray of light striking a mirror at a certain angle is reflected at the same angle (Fig. 5). This theory, although it explained many of the facts known about light, did not explain them all, and therefore could not be correct.

His friend and contemporary, Hooke, in the year 1664, wrote these memorable words :

" Light consists of a very minute vibrating movement of an elastic medium, which is propagated with great rapidity, but not instantaneously, in straight lines that proceed like the radii of a sphere from a central point common to all."

He must therefore be regarded as the originator of the true theory of the transmission of light by luminous waves.

He got the idea, but he failed to perfect it. In the year 1690 Huyghens wrote a tract on light, in which he made great advances on the knowledge of Hooke, and he may, therefore, be called the real founder of the wave theory of light. He was right in his facts, but they remained overshadowed by the great authority of Newton, who had held another theory. At length, in the year 1773, Thomas Young was born. He was the man who discovered the key by which the obscure inscriptions of the ancient Egyptians were deciphered. This intellectual giant studied the laws by which waves seemed to move. He perceived the analogy between the motions of waves and the transmission of sound through the air by air-waves. He applied the theory to light,

and proved that light travelled by means of waves or vibrations through a refined substance which fills all space, called the ether.

This important discovery needs careful explanation. We must first understand the nature of wave-motion. It is a delightful recreation to stand on the sea-shore and to watch the waves coming in when a good sea is running. We see the approach of

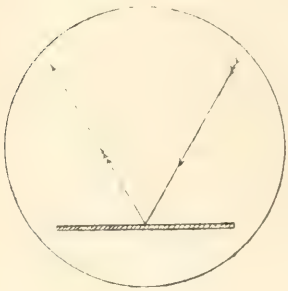

Fig. 5.

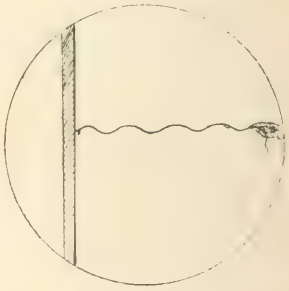

Fig. 6.

a large wave which is out a considerable distance. It attracts our attention because it is larger than the others. They all reach the shore in a regular procession; at last the big wave approaches, rushing on with majestic force. It towers up until its edge becomes thin, and then it breaks into foam and dashes on the shore. This is what we see, but did that wave really approach us? The wave did, but the water of which it was formed did not. Some distance from the shore some pieces of cork were floating, we saw them mount up on the front of the wave and

disappear down its back, but they rose and disappeared over every wave which passed under them. They were not carried forward by them, for they remain where they were before. We conclude, therefore, that while the wave rushed forward, the drops of water of which it was composed simply moved up the front and down the back. We can imitate the true motion of a wave by means of a long string (Fig. 6). Fasten the string at one end to a nail in a wall, and having stretched it fairly tight, move the other end up and down rapidly with the hand. This up-and-down motion will pass in waves along the whole length of the string until it is stopped by the nail in the wall. If you have ever seen men shaking a long stair-carpet, you observe that as they move their arms up and down at either end, the carpet moves in waves from one end to the other, although the carpet itself remains over the same piece of ground. Still, to make waves at all the substance of the string or the carpet was necessary to enable them to be formed. Sound reaches the ear by means of waves formed in the substance of the air. If a tuning-fork were placed in a vacuum under a glass shade, out of which the air had been pumped, it might be caused to vibrate, but no sound could be heard; whereas if the air were let in again, and the tuning-fork were set in motion, the sound could be heard clearly. But the waves of light are independent of the presence of air, for light passes freely through the glass shade whether the air were pumped out of it or not.

Think of the problem which had to be solved. Waves need a substance to be set in undulatory motion before they can possibly exist. There must be water on which water-waves can be formed, there must be air or water through which sound-waves can pass, but this substance called ether, which vibrates so as to allow the waves of light to rush along, existed in a vacuum, and in the substance of the glass shade itself and in all space. No one ever saw or felt or heard this substance, but Young reasoned that it must exist, and further that it must pervade all space between and beyond the stars, also the interior of solid bodies such as iron, glass, or diamond. The pace at which light can travel through it in all directions proved that its particles must lie very close together, for, unless they were, the vibrations of light could not pass from one particle to another with such amazing rapidity. For instance, stepping-stones across a river are fairly far apart, and we pass from one to another at a slow and deliberate pace. But if the stepping-stones were placed quite close together they would form a continuous road along which men could run at top speed.

The train can attain great speed on a smooth rail in which the particles of iron lie close together. It runs at the rate of one mile in a minute, but the waves of light travel along this medium at 186,000 miles a second—that is, while a fast express train was running one mile, light would have travelled 11,160,000 miles.

When a ship sails through water she pushes the water aside, and it closes up when she has passed; but the solid earth does not push the ether aside, rather the ether passes through the earth and everything in it, as the air of a room would pass through an open wire sieve which you might hold in your hand and move to and fro.

These may seem to be fanciful theories, but they are known to be facts, because every fact in the

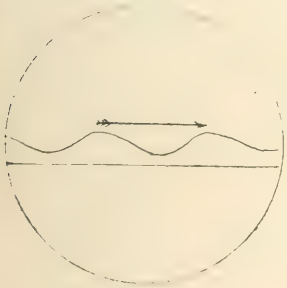

FIG. 7.

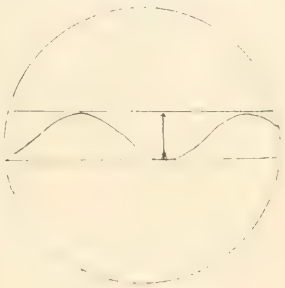

FIG. 8.

phenomenon of light can be explained fully on the assumption that this substance called ether exists throughout all space, and that light is propagated in all directions from any given point by creating waves or vibrations in this substance.

We must remember two terms used in describing waves. The *length* of a wave is the space measured from crest to crest (Fig. 7).

The *amplitude* of a wave is the space measured from top to bottom—that is, the vertical line drawn from the crest to the sinus or hollow (Fig. 8).

There is a difference between the motions of waves of sound and waves of light. A wave of sound is caused by the motion of a vibrating string or tuning-fork transferred to the air. For instance, the tuning-fork when vibrating moves its prongs to and fro sideways (Fig. 9). When the prong moves to the right it pushes the air to the right and condenses it, when it moves to the left it draws it back and rarefies it. The waves of sound are represented by thick

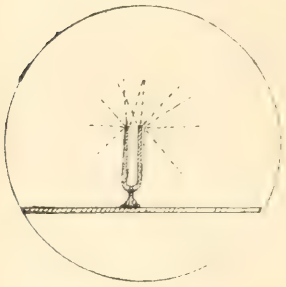

FIG. 9.

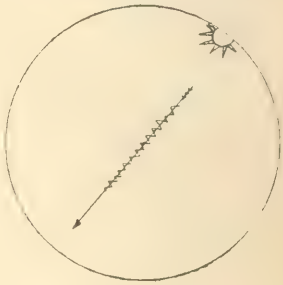

FIG. 10.

lines and thin lines proceeding in all directions from the fork.

These waves progress in the same direction in which the sound travels; whereas, the waves of light advance by vibrations across the direction in which the ray of light advances, just as the particles of water in an advancing wave do not move forwards and backwards, but up and down. Of course the terms up and down only apply to waves on a surface, but in space there is no top or bottom, so that the

waves of light vibrate across the line of advance in every direction (Fig. 10).

The next point we have to consider is the effect of waves on one another. If a small stone were dropped into a perfectly smooth pond, it would make a depression, but the next instant the water so depressed would rise again, and rise higher than it was before. This repeated motion would be the centre of a number of waves which would advance from the spot in widening circles, but if two stones were dropped in at a short distance from each other, the waves from each would soon cross one another (Fig. 11). If, instead of watching two stones falling in, we witnessed the coming on of a shower of large drops in a smooth pond, we should see the phenomenon of the interference of waves. The first few drops would make circles, but soon many drops would make so many crossing circles that we could only observe a general roughness. Sometimes the crest of one wave would coincide with the crest of another. The result would be a wave of double height. Sometimes the crest of one would coincide with the hollow of another, in which case there would be no wave, but a flat surface. At that point, for a moment, the water would not be moving either up or down, and would therefore be at rest.

Now the waves of light travel along the ether, vibrating not merely up and down like water-waves, but in every direction across the line of advance. So long as they are free and unimpeded, they do not interfere with one another, but when they are dis-

turbed they do interfere. When the crest of one light-wave coincides with the crest of another the light is intensified, but when the crest of one wave falls on the hollow of another, the vibration is counteracted and the result is that at that point, for the moment, there is no movement in the ether, and the result is darkness.

Think of what takes place when you enter a dark room with a candle. Before you entered the ether

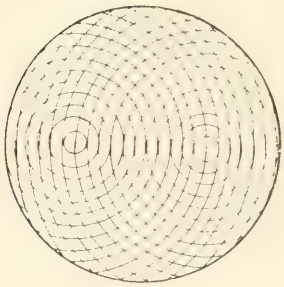

FIG. 11.

FIG. 12.

in that room was at rest, therefore there was darkness. When you introduce a candle the white-hot particles of carbon are moving with intensely rapid vibrations in the flame. They set the ether in vibration in every direction, issuing from the flame as from a point. They are so minute that although we can speak of one ray of light, we really see a great number acting together, which we call a beam of light, just as a beam of wood is made up of a vast number of fibres of wood. These beams radiate

from the candle, and are reflected from the walls and ceiling as diffused light, because the surfaces are not polished. If the walls were hung with mirrors we should see, not only reflections of the candle, but many reflections of reflections, so that we should seem to stand in a vast chamber illuminated by many candles. Magic rooms are constructed on this principle, the effect being caused by the multiplied reflections from mirrors placed at various angles.

When we understand the simple law of reflection, viz., that a beam of light falling on a polished surface is reflected at the same angle as that by which it fell on the surface, we can find much interest in studying reflections in still water, or in understanding the reason of the colour of ripples which are little waves. When we are standing on ground ten or twelve feet above the surface of a calm lake, we never see an exact reproduction of the opposite bank in the water. What we do see is the view of the bank which would be seen by the eye of one swimming in the water at the point where the ray is reflected (Fig. 12). Sometimes amateur artists, through ignorance of this fact, make great mistakes in drawing reflections. In the case of rippled water, the main thing seen is the reflection of colour. When the clear east wind blows, a rippled lake looks intensely blue. The reason is that each wavelet presents a sloping surface to the eye, and therefore, instead of reflecting the pale blue or grey which we see in front of us in the sky near the horizon, the wavelet is sending to the eye beams of light reflected from the deep blue of

the sky overhead (Fig. 13). What we see in the lake is the same blue which is in the zenith, only it is not so bright. The difference in brilliancy is caused by the fact that whereas the sky sent down to the wave a beam of light of full brilliancy, only part of it was reflected towards the eye; the other part entered the water and was absorbed.

The amount reflected and the amount absorbed

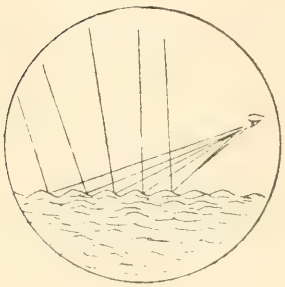

Fig. 13.

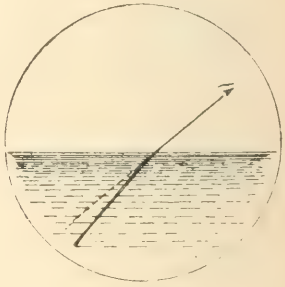

Fig. 14.

depend on the sort of surface on which the ray of light falls, and also on the angle at which it falls.

When we look at ourselves in a mirror the ray of light falls, let us say, from our eye in a perpendicular direction on the glass, and is sent back to the eye along the same line. We do not see much of that reflection, because out of every thousand rays which fell on the near surface of the glass, only 25 came back. The rest went through the glass to the back surface. But the rays which went through the glass to the far side were there reflected in a per-

pendicular line from the film of quicksilver or mercury which adheres to the back. Of the 1000 rays which went in about 600 returned, the remainder being absorbed. Now if, instead of looking at ourselves in a mirror, we had to be contented with a deep, calm pool of water, looking straight down at it we should get back only 18 rays out of every 1000 which went from our face on the water, for all the rest would go into the water and be absorbed.

But the amount of reflected light is far larger when the ray of light falls on the water at an extreme slant. Then about 720 rays are reflected out of every 1000—that is, a greater proportion of rays are reflected than can be got from a mirror of pure mercury when looked at vertically.

When water lies thus in its best position for reflecting light, nearly 300 rays out of every 1000 are absorbed into its substance. We conclude, therefore, that light passing through air, and falling on any substance denser than air, is not totally reflected.

What becomes of the remainder?

When light passes from a thin medium like air into a denser medium like water, the ray is bent downwards towards the perpendicular. We do not see the bend in the ray, but we see its effect. To our sight the ray is always assumed to be straight, therefore the object in the water on which it falls seems to be raised upwards (Fig. 14). The real ray is represented by the solid line. What we see is represented by the dotted line. Hence a straight stick

dipped in water appears to have its wet end raised and it looks as if it were bent upwards. Place a coin on the bottom of an empty basin, and stand to one side so that the coin is just hidden by the rim of the basin. Now let some one pour in water and fill the vessel. Immediately the coin seems to rise so that you can see it, and the basin seems to be more shallow than it really is (Fig. 15).

Place your foot in water. It appears larger. The

FIG. 15.

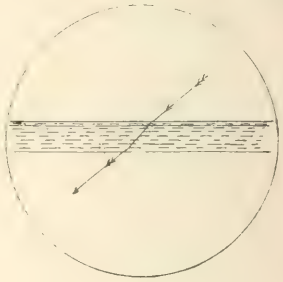

FIG. 16.

reason is, not that it has been magnified, but as it seems to be brought nearer, it looks as much larger as it would look had it been really brought nearer. Every ray of light entering a transparent but denser medium is bent, and on emerging from that medium it is re-bent again into its original direction, and assumes its former course, only on a slightly lower plane (Fig. 16).

But the reversed process takes place when a ray of light passes from a denser to a rarer medium,

when, for instance, it passes from water into air or from dense air into thin air.

When air rests on the heated surface of the sand of the desert it is made, by expansion caused by the heat, rarer or thinner.

A distant object reflecting light throws a beam at an extreme slant on this layer of thin air. That beam, when passing from the denser air into the layer of rarefied air, is not bent downwards, but upwards at a low angle. Consequently the dry sand of the desert appears as a reflecting surface, and looks like calm water reflecting with brilliancy (because the total sum of light is reflected) distant objects such as palm-trees. This is the mirage of the desert. The effect is often seen when one swims in the sea in the morning. The sea, being rippled, can form no true reflection of the distant coast, but the air has been chilled during the night except the layer of air lying on the water, which is still warmed by the heat of the previous day. The eye of the swimmer being only a few inches above the water, perceives the image of the distant coast reflected on the layer of warmer air with wonderful clearness, but when standing on the rocks some feet above the surface of the water, the mirage can no longer be seen, because the angles of sight and reflection are both increased. The same phenomenon may be seen, under the same atmospheric conditions, from a row-boat on an extensive sheet of water.

This peculiar bending of the rays of light when they pass from a medium of a certain density into

a medium of different density, whether it be greater or less, is called *refraction*. It is important that we should remember very distinctly these two terms *reflection* and *refraction*, so as to know at once the difference between a reflected ray of light and a refracted ray (Fig. 17). The thin dotted line is the reflected ray turned upwards from the surface of the water, and the thick line is the refracted ray turned downwards through the water.

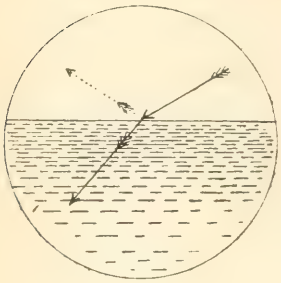

FIG. 17.

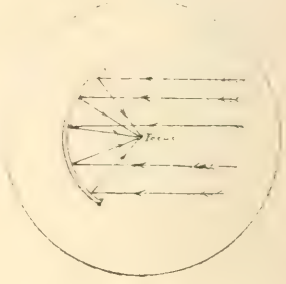

FIG. 18.

This refraction is a most important property of light, for by means of it clear sight has been made possible. Only for it, we might perceive light, indeed, but we never could have seen any object distinctly, for clear sight depends on the rays of light being brought to a focus, and this is done by refraction, or power of bending. This thought brings us to the consideration of lenses through which light is refracted.

No matter how finely curved glass may be polished,

the rays of light are so exceedingly minute that the curves may be regarded as a series of straight lines at different angles. We see here (Fig. 18) the rays of light falling on these surfaces in a concave mirror by which they are reflected into a focus. In the next (Fig. 19), we see them refracted passing through a convex lens, and in the next they are refracted passing through a concave lens used by short-sighted people (Fig. 20).

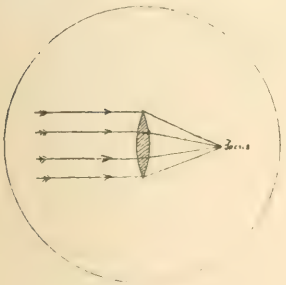

FIG. 19.

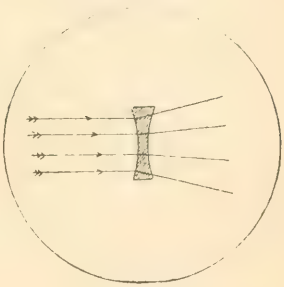

FIG. 20.

Owing to these laws of refraction combined with reflection, optical instruments with reflecting mirrors and refracting lenses have been constructed. The magic lantern is one of these (Fig. 21). Behind the light there is a concave mirror to reflect the light forwards ; in front of the light there is a convex lens to refract the light through the slide ; in front of the slide there are other refracting lenses by which the image of the picture on the slide, greatly enlarged, is thrown on the screen.

In the microscope the light of the sun or of a lamp

is reflected by a concave mirror on the object. Then the image of that object is magnified by refracting lenses and brought in a focus to the eye.

In telescopes the image of a distant object is brought to a focus by the object glass—that is, the glass in front—and then the image at the focus is magnified by the lenses in the eye-piece. In a reflecting telescope the aperture in front is large, and the rays of light are reflected from a concave mirror placed at the bottom of the tube and brought to a focus, which, as in the refracting telescope, is then magnified by the lenses in the eye-piece.

We cannot enter here into the details of the construction of these wonderful instruments, and there are many who do not possess them, but we may consider as a familiar illustration of the practical use of the laws of reflection the well-known and serviceable bicycle lamp.

There is a principle in mechanics that no machine can produce more force than the energy put into it. As a fact there is always a loss or leakage of force in any engine that was ever constructed. This principle applies to light and to machinery contrived so as to utilize it best.

The lamp cannot produce more light than the flame which is burning in it gives out. When a lighted candle is placed on a table and a man sits on a chair at the fireplace and reads a book, how much of the light of that candle does he use, and how much is wasted ? Let us say that the page of his book is six inches square. Whatever light falls

on half a square foot represents the amount used by him. But suppose the room measures 10 feet every way. Neglecting the floor, we have 100 square feet in the ceiling, and 400 square feet in the four walls. Total, 500 square feet illuminated by the candle, and another 100 square feet wasted on the floor. As the man is nearer the candle than the wall, let us allow him for his book four times or sixteen times the amount of light that falls on an equal space of

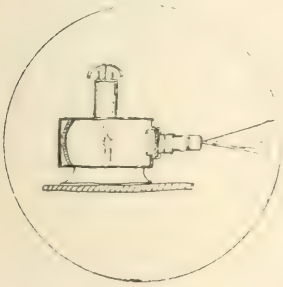

FIG. 21

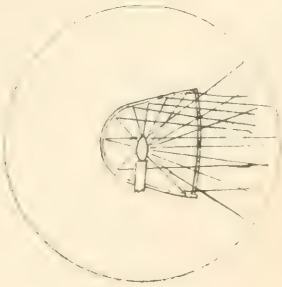

FIG. 22.

the wall, still the difference between what he uses and what is wasted on the room is very great. So if the small flame in a bicycle lamp were shining in the open on a calm night, the amount shining on the road would be very small in comparison to all the rest which would be lost in the surrounding darkness. The idea in a bicycle lamp is to place above, below, behind, and at both sides of the flame a curved reflector, so that all the rays of light which would otherwise escape in these directions may be caught, turned from their course, and sent out in

front to increase the light of the rays which would naturally fall in front (Fig. 22).

The same principle is applied to the searchlight employed in the Navy. A coastguard officer said that no light can be made for a searchlight brighter than 25,000 candle-power, but that by means of the reflectors a beam of light of 1,000,000 candle-power can be sent flashing in one direction. These facts show the practical use of the laws of reflection.

I have spoken of "candle-power." Let us see how the intensity of light is measured.

If a drop of oil were put in the centre of a white sheet of paper it would form a spot. If you looked at the paper with a light between you and it, the spot would appear dark and the paper bright, because the light falling on the paper would be reflected back towards your eye, and the light falling on the spot would pass through without being reflected.

But if the light were held behind the paper, the spot would appear bright and the paper dark.

Now if the paper were held between a candle and a gas-jet and looked at sideways, it could be moved either towards the gas-jet or the candle until the two lights were balanced exactly, and the spot would disappear (Fig. 23). By measuring the distance between the candle and the paper, and between the paper and the gas-jet, the relative brightness of the two lights could be determined.

Another most useful appliance of the laws of reflection and refraction has been made in the construction of the lantern of a lighthouse. It is obvious

that the object to be attained was to prevent the light from being wasted by shining on the sky or the ground, and to send out all the rays, if possible, in the direction of ships sailing on the sea. This was the requirement of lighthouses situated on isolated rocks like the Eddystone. When the lighthouse stood on the shore, it was further necessary to save the rays of light shining towards the land. For the latter purpose metallic reflectors were placed

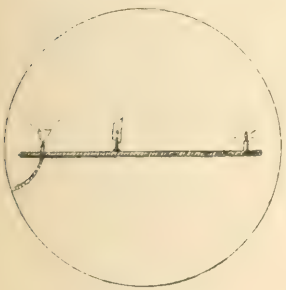

FIG. 23.

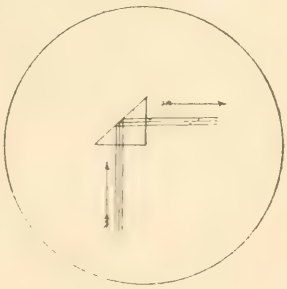

FIG. 24.

behind the light by which all the rays shining landwards were intercepted and turned in a forward direction towards the sea, as in the bicycle lamp. But it may be seen that by this means many rays went upwards and many downwards which were lost to the mariner.

Also, as we have already said, in all reflection from metallic surfaces only some rays were reflected and the rest were absorbed and lost. To avoid this defect Fresnel proposed that refracting lenses should be used instead of reflectors. By a lens

shaped in section like a triangle, total reflection can be obtained (Fig. 24). The light passing into the lens is bent or refracted so that it cannot escape except in one direction.

The flame, made either by gas or oil or electricity, is placed in the centre of the lantern, and its rays fall on a series of these lenses so that the light is totally reflected by them in a horizontal plane. Some lanterns have six sides, and are made to revolve round

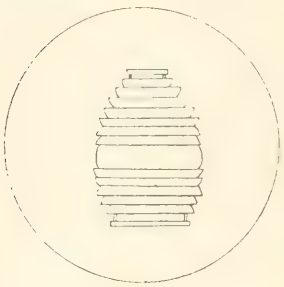

Fig. 25.

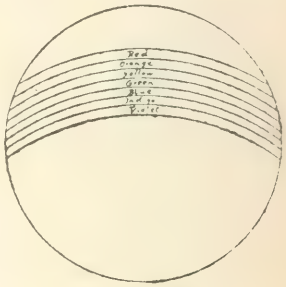

Fig. 26.

the light. The result is that when one of the sides comes opposite to the ship the whole light is sent in that direction, and then when the corner is opposite the ship scarcely any light is seen. The effect is to produce an intermittent light, alternately bright and dim, and by the number of bright shinings in each minute the individuality of the light is known, as the number of flashes per minute are recorded in the ship's books. In a fixed light, which is not intermittent, the lantern is usually round. The principle of its construction is here shown (Fig. 25).

We have now considered the nature of light, which has been discovered to be undulations or waves causing vibrations in the substance called the luminiferous or light-bearing ether. We have seen what is meant by reflection and refraction, and the uses which have been made of the knowledge of these laws. Our next subject will be the phenomenon of colour.

II

COLOUR

THERE are very many people who perceive colour, who enjoy looking at various colours, and who, perhaps, have considerable taste in matching colours and in choosing shades and tints which harmonize together and give a pleasing effect, but who have never asked the question, What is colour?

We have to try to answer that question now, and if we succeed in understanding what it is, and the cause of its various hues, and the laws by which it is regulated, we shall have a deeper interest and greater pleasure in the observation of colours in the future.

We are accustomed to associate colour with things, and to consider it as a part of the thing itself. A red dress is red, and cannot be anything else unless it is dyed another colour. One flower is yellow, like the buttercup, and another blue, like the forget-me-not. Other substances, like air, and water, are transparent and have no colour. So we think, until we look thoughtfully into the great book of Nature, and then we find that our conceptions are wrong.

For instance, on a bright, showery afternoon we happen to be walking with our back towards the sun, and our faces towards a shower-cloud which has just passed over us. On that shower falling from the cloud we see a gorgeous rainbow. On the outside of the arc red appears, it merges into orange. This passes into yellow, and the yellow into green. Next the green is a band of bright blue, and then another of indigo, and on the inside of the arc we see violet (Fig. 26). We notice further that these tints blend into one another, so that there is no sharp dividing line between them. No red, green, or blue dress ever approached the beauty and delicacy of colour exhibited in the rainbow, and yet we know that the only materials in that shower were some thousands of drops of transparent water falling through transparent air. As we gaze at the beautiful sight a small cloud comes between the sun and the shower, and in a moment the whole exhibition of colours disappears, and the shower looks like a grey sheet.

It is evident that all those splendid colours came directly from the sunlight when it shone upon the drops of the falling shower.

What really happened was that the sun told us a great secret, viz., that its rays, which usually seem as white as it is itself, were composed of all the colours which we saw in the rainbow.

The drops of rain had divided up the rays of light into their component parts, so that we could see each part separately. This process is called the *dispersion*

of light. In the former chapter we considered all the parts of a ray of light as acting together. We saw that a ray can be reflected and refracted. We have now to consider how the parts act when dispersed or separated the one from the other. We shall return presently to the explanation of the phenomenon of the rainbow, but we must first consider another plan by which we can study the dis-

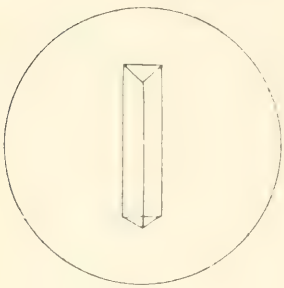

FIG. 27.

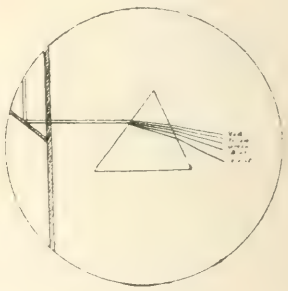

FIG. 28.

persion of colour without waiting for a bright, showery day.

Some years ago it was the fashion to have candlesticks ornamented with glass droppers, which were often placed on the drawing-room mantelpiece.

Chandeliers and gasaliers were ornamented in the same way. These glass droppers were long pieces of glass with three sides. If one were broken across, the ends were seen to be shaped like a triangle (Fig. 27). On a sunny afternoon, when the sunlight shone into the room and lit upon one of the glasses, some-

where on the wall a bright little bit of rainbow colours appeared. The glass was a prism, and it dispersed the light into its component parts.

Let us see how light is dispersed when it passes through a prism (Fig. 28).

The beam of sunlight is here represented coming through a small hole in a shutter and sent across a room by a reflecting mirror placed outside the window. It enters in a straight line until it meets the prism, which presents to it a sloping side.

The vibrations or waves of light cannot travel through glass at the same speed as in the open, and some of them are more bent or refracted in passing through the glass than others. Therefore they do not emerge from the glass as they went in as a point, but are dispersed as a band. The least bent are the red waves, and the most bent are the violet. This coloured band is called the spectrum.

Let us see how this band is formed.

When light shines from an object its rays travel in straight lines in all directions. If a large muffed glass globe be placed round the light of a lamp, every particle of the globe is illuminated, top, bottom, and all round. The rays pass through it and illuminate every square inch of the walls of the room. Now when rays of light shining from a bright object are admitted into a dark room, or a box, through a pinhole, it is evident that they must form a reversed image of the object (Fig. 29). The ray from the top of the object must pass through the pinhole in

a straight line, and strike the lower part of the side of the box; the ray from the lower part of the object must pass upwards through the pinhole, and strike the upper part of the side of the box.

It is so with all the rays; those on the right go to the left, and those on the left to the right.

When we walk under trees on a day when the sun is shining overhead, we see the pathway mottled with beautiful circular patches of light. We look

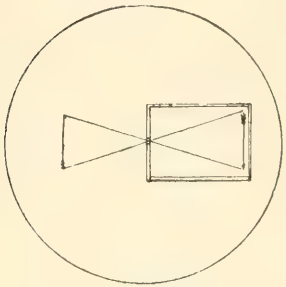

FIG. 29.

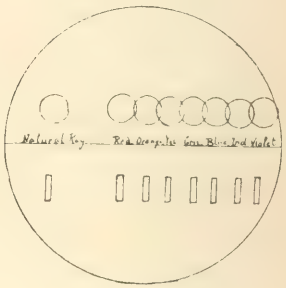

FIG. 30.

up towards the trees, and see that there are little gaps between the leaves through which the bright rays from the sun pass. These small gaps may be compared to the pinhole, and therefore what we see on the walk are really small reversed images of the sun itself.

If light clouds are passing over the sun, but not concealing its shape, we can see the image of those clouds moving in opposition to their true direction in every single circular patch of light on the walk.

We do not see them when the patch of light is large, because it is then made up of a number of images, of the sun which overlie one another, and thus destroy the definition of form.

Now the ray which formed the band, after passing through the shutter, makes an impure spectrum whenever the hole is round. The band is then composed of images of the sun which slightly overlap one another (Fig. 30). This fact explains why the colours of the spectrum gradually merge into one another. If, instead of a round pinhole, we admit the rays of light through a very narrow slit, this overlapping of the images of the sun is avoided. We find that each colour has its proper place in the spectrum band.

Let the light be admitted through the slit without a prism being placed in its path, the light will appear directly opposite on the spot marked natural ray. Now intercept it by a prism and cover the slit with a piece of red glass, the light is simply moved to one side to the place marked red. Next, remove the red glass and replace it with a piece of violet glass, then the light is moved further to one side to the place marked violet. Introduce orange, yellow, green or blue glasses, and each slit falls into its proper place ; by this we know the refrangibility, or the power of bending, possessed by each coloured ray of light. Having thus examined the light of the sun, we think at first sight that the band of coloured light is continuous, showing that every shade of colour from red to violet is

found in sunlight, so that, although Newton spoke of seven colours, there are really, if we include the intermediate shades, hundreds. We know, for instance, that there are many shades of red ranging from deep crimson to light pink, and it is so with all the other colours, such as the various hues of green which we see in grass and the leaves of trees. But, as a fact, we do not see nearly all the rays of light in the spectrum, for outside the red end lie rays of heat which we can feel but cannot see, and outside the violet end are rays which are invisible to the eye, but which powerfully affect a photographic plate. These are called the ultra red and the ultra violet rays. When the spectrum band is accurately adjusted so as to be as pure as possible, it was found not to be as continuous as it appeared to be at first sight. Wollaston discovered that it was crossed by dark lines, as if some colours were missing. He detected four such lightless lines. But Fraunhofer caused the spectrum to be formed on the object glass of a telescope, which was then magnified by the lenses in the eye-piece, and he counted 400 dark lines or gaps in the band of light. As he first measured and investigated them, they have since been called the Fraunhofer lines. Brewster, with a better apparatus, counted 2000, and it has since been discovered that they are really innumerable. Fraunhofer numbered the more prominent lines by the letters of the alphabet, the most famous being the line D, to which we must refer afterwards. So far we have seen that all colours are formed by

the component parts of the rays of sunlight. We know by practical experience that other lights, such as candle-light, do not contain in the same proportion all the colours of sunlight, for if we tried to match coloured ribbons by candle-light, we could see the difference between some colours, but not between all, and if we painted a picture by candle-light, we should make serious mistakes which daylight would reveal.

We are now in a position to understand how colours appear on substances.

Light shines on an object such as cloth. If we took a piece of black cloth and placed it on the spectrum band of colour, all the colours would disappear, because all the colours would be absorbed by the black cloth, and none of them would be reflected back towards the eye so that they could be seen. Any black substance is black because it absorbs the rays of the spectrum, including the ultra red rays which are known as heat. When the sun shines on our black coat we feel the heat of these, because they go in and do not return, except in a small proportion off the polished surfaces of the fibres which form the cloth.

When the sun shines on a white hat most of the rays are reflected back in the form of whiteness, and only a small number pass in and are absorbed. Hence in great heat people wear white clothes. A black kettle is better than a bright one for boiling water, because, being black, it absorbs the rays of heat sent to it by the fire, and they pass into the

water. These facts explain the nature of blackness.

Now what about red? Place a red piece of cloth on the red part of the spectrum, and it shines with an intense red, because, instead of absorbing, it reflects back the red rays towards the eye. But if we place the red cloth on the green portion of the spectrum, it appears jet black. The only rays which reached it were green rays, and it absorbed them all, so that it had none to return, hence it looked black. It is evident, therefore, that the red colour does not belong to the red cloth as a property, for if there were no red rays in the light which shone on it, it could never look red. We see, then, that the colour of any substance depends on two things, viz., its power to absorb and its power to reflect certain rays of light. We never see the rays which it absorbs, but only those which it reflects or sends back towards the eye.

Take an illustration. If seven people went up to a house seeking admission, and all were let in at the door, the house might be called black. If all were turned away and the door shut in their faces, the house might be called white. If six were admitted and one were sent about his business, that one would represent the colour of the house as seen by the eye. When light shines on a flower, not only seven, but thousands of rays of light seek admission to its substance. They all enter its hall door—that is, all pass into the substance of the petal—until they reach the inside, where several remain, but one is

turned out and rushes off towards our eye to tell us the colour of the flower.

In what follows we must remember that we are dealing with pure light, not the colours of paints, which we shall explain presently.

A diagram has been constructed called the triangle of colour (Fig. 31). Where all the lines meet there is white, where two are joined together by a straight line which passes through the white point, they also when mixed produce white. Every one knows that if blue and yellow paints are mixed together, the result is green, but it is not so when the blue and yellow lights of the spectrum are imposed on one another, for then the result is a white light.

The triangle of colour shows the colours which are the opposites of one another, just as black is the opposite of white. These opposites are called complementary colours, for the one fills up what was wanting in the other to produce white.

Professor Tyndall quotes a work by Christian Ernest Wunsch, published in Leipzig in 1792, in which the author says that there are neither five nor seven, but only three colours in white light.

The way he proceeded was to produce five spectrum bands of colours by five prisms and five small apertures. He mixed the colours in pairs and in other proportions. By this means he discovered that red was a simple colour which could not be decomposed, that orange was made of intense red and weak green, that yellow is a mixture of intense red and intense green, that green is in itself a simple

colour, that blue is compounded of pure undiluted green and pure violet, that indigo is a mixture of pure violet and weak green, and that violet was a simple colour incapable of decomposition. He also discovered that yellow and indigo lights produced white, while yellow and bright blue made white also, but with a slight tinge of green.

These facts were subsequently adopted as proved by Young, and further amplified by Helmholtz, so that the theory is now known by the name of the Young-Helmholtz theory, about which we shall have more to say when explaining the phenomena of vision.[1]

These results obtained by super-imposing the coloured lights in a spectrum are quite contrary to those obtained by mixing paints of similar tints. We must therefore see why the colours of paints are different from coloured lights.

Paints are made of certain coloured minerals, earths, or vegetable matter very finely ground and mixed with transparent oil or water.

If we took a white plate and dipped it in shallow water, its colour would remain white, because only an imperceptible portion of the light would be absorbed by the water. But if we let it sink to the bottom of a barrel of water, we could see the colour of the water. The plate receives the rays of light which have passed through the water, and it reflects them back towards the eye. Now the most minutely-

[1] Cf. p. 104.

ground portions of matter behave exactly like the white plate. They catch the rays of light falling on them and reflect them back. When at sea in a boat, if the water is deep it seems to be black, because the rays of light enter and pass into the depths and none are reflected back, but if the boat is in shallow water the light reflected from the sand at the bottom shows the water to be a beautiful green. It is all the same whether the reflecting matter is opaque or transparent. Examine snow with a pocket lens and each crystal is seen to be formed of transparent ice, but the white light is reflected from the surfaces of the crystals, and the snow appears dazzling white.

We notice the same fact when we examine common salt or powdered alum, or when we see the green of sea-water reflected from the surfaces of small bubbles under the water when a wave is breaking into foam.

Now let us suppose finely-ground particles of cobalt blue and yellow ochre to be mixed together in transparent oil. The white light shines on the particles through the oil, and it is reflected back, but only in part, for the cobalt blue catches all the red, orange and yellow rays and absorbs them. The yellow ochre particles catch all the violet, indigo and blue rays, and prevent them from returning, therefore the only rays left, which can get in and come out again, are the green rays, and therefore the paint appears to be green. This illustration applies to all the other colours, and explains the

reason of the peculiar colours of paints, and why they differ from the mixture of coloured lights.

Having thus seen that no colours belong to things in themselves, but that all are the result of the structure of things by which they absorb some parts of the rays of light and reflect other parts towards the eye, and that the most brilliant colours are formed by the reflection of light from the surfaces of transparent bodies as well as from the surfaces of what are called opaque bodies, let us consider in some detail the explanation of the beautiful colours which we see in a rainbow.

We shall first investigate the laws of reflection and refraction as illustrated by a globe of glass filled with water upon which a ray of light is caused to fall through a slit, which arrangement represents the sun shining on a round drop of water as it falls from a cloud.

Let a ray of sunshine be admitted through a small slit in the shutter, and made, by means of a sloping mirror outside, to go straight across the room to a large stretched sheet. In the centre of the sheet is a hole through which the ray of sunlight can pass to a globe of water 1½ inches in diameter, placed behind the sheet.

The part of the ray which strikes the globe fair in the middle passes in to the far side, and is sent back straight in the same direction by which it entered. The part which strikes the globe near the edge is at once refracted towards the back of the globe, where it is reflected on the inside polished surface towards

the other side, and it is refracted again when it leaves the globe of water and passes out into the air. It is found that the direction which it takes on leaving the globe varies from $42\frac{1}{2}$ degrees to $40\frac{1}{2}$ degrees—that is, something less than the half of a right angle. The result is that a beautiful rainbow appears on the screen all round the hole, with the red outside and the violet inside the circle. We see (Fig. 32) the course taken by the ray of light from the time

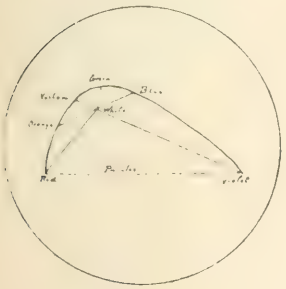

FIG. 31.

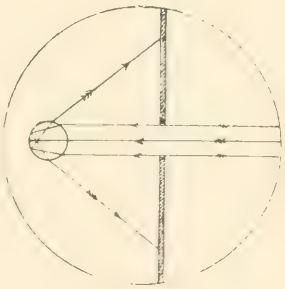

FIG. 32.

it passed through the hole in the screen until it returned dispersed into rainbow tints.

When we can thus make a rainbow artificially, we can explain the phenomenon of nature. If the sun were a point of light we should have very thin bands of light, but as the sun is large each band is broad.

One more question has to be answered, viz., Why do the colours appear? Descartes discovered the answer. He made careful calculations following the

course of each ray as it came from the sun into the drop of water, and returned from it to the eye. He found that, at one exact angle, the rays which are reflected from the back of the drop came out parallel to each other, and therefore were able to preserve their intensity, while the other rays going out in divergent directions were practically lost to sight and merged in general light. The red rays emerged parallel to one another at an angle of $42\frac{1}{2}$ degrees, the violet at an angle of $40\frac{1}{2}$ degrees, and the others at intermediate angles.

The same principle explains the secondary rainbow which appears sometimes outside the primary one with the colours reversed—that is, with violet on the outside and red on the inside of the arc. Full details of this phenomenon can be read and studied in books on optics.

When we understand how the rainbow is formed, we are struck by the enormous rapidity of the action of light. The little drops are falling in thousands through the air. Only for the millionth part of a second can each drop be in the precise position and at the exact angle so that the phenomenon can take place, yet in that inconceivable fraction of a second the ray has time to enter the drop, accomplish its reflections and refractions, and rush out towards the eye, in which it is again refracted, focused, and at last it communicates its vibrations to the retina, and then it is absorbed and produces the sensation of sight.

The rainbow is one of the beautiful marvels of

nature. So transient is the operation! And because it is so transient, we must further conclude that one drop can only send its ray of light to one eye. The other eye is a long way too far on one side to be affected. Another drop sends its ray to the other eye. Consequently two people standing close together never see the same rainbow proceeding from the same drops. Also it is evident that if we see a rainbow reflected in calm water, we really see two rainbows—one seen from the point where we stand, and the other seen from where we should see it if we were swimming in the water with our eyes close to the surface. It is hard to realize, as we gaze on a rainbow which seems so steady on a calm summer afternoon, that all these operations of amazing rapidity and complexity are going on around us, yet this is the knowledge which we gain by the study of the book of Nature.

Another phenomenon, full of interest, which needs explanation is the colour of a drop of oil or turpentine when it falls upon water. As we look upon the turpentine in a bottle it has no colour, the water also is quite colourless; but the moment the drop falls and spreads out on the surface of the water, we see a most beautiful array of all the colours of the rainbow, which flash out in every direction, and which change incessantly from red to green or from blue to violet. Where do these colours come from, and what causes them?

They may be seen in another way. When we were children, if we were natural children, we took great

delight in blowing soap-bubbles. I fear our chief interest was to see how large we could make the bubbles before they burst, but we may have noticed how pretty they were, decked on all sides with gorgeous rainbow tints.

Now, long ago, three very wise and grave philosophers spent hours in blowing soap-bubbles. Their names were Hooke, Boyle, and Newton.

No doubt, if some members of the household caught them in the act, they wondered that grown men of age and sense could not find for themselves some more manly amusement. But they were not amusing themselves ; far from it. They were thinking deeply on the cause of those colours which they observed, and in thus discovering the cause, they laid the foundation of the great theory that light was really caused by the vibration of waves in the invisible ether, and that colour was the result of the dispersion of the rays of light into their component parts, each part vibrating in waves of different lengths. They found out from watching soap-bubbles that the red waves were the longest, that green waves were of medium length, and that violet waves were the shortest—just as Atlantic rollers are longer than local wind-waves, and these again are longer than ripples.

Boyle noticed that the colours were arranged in circles round the parts of the bubble which were the thinnest. Newton proceeded to produce these circles by another means, which we shall presently describe, and he was able to measure definitely the

lengths of the waves which gave forth the various tints of coloured lights. For the present let us return to the soap-bubble and inquire what takes place when a ray of light shines upon it.

However thin a soap-bubble may be, it has still some thickness, therefore every part of it has two surfaces, one the outside and the other the inside of the film, and the fluid substance between these two surfaces is transparent. The same effect is seen permanently on a very thin bubble of glass. When the ray of light strikes upon the outside surface, part of it is reflected back at an angle equal and opposite to that by which it fell on it, but the other portion of the ray passes through the transparent medium until it reaches the inside surface, from which part of it is also reflected backwards. We may neglect the portion of the ray which goes into the bubble and is lost to sight.

We understand the matter better if instead of speaking of the parts of one ray we think of two rays close together, running a race to reach the bubble, then to turn back, and reach the eye of the observer. We may compare them to two boys running a race in which they kept step together. At the turning-point there are two posts, one a foot behind the other. One boy, whom we call A, has only to touch the near post, turn round, and run for the starter. The other boy, B, has to pass the near post, touch the far post, and then turn round and run towards the starter. The result of having to touch the far post would be that on the return journey, boy B would

be out of step with boy A. Not so if the far post were exactly one step beyond the near post, for then he would take a whole step to reach it, and another whole step to return, so that although he would be two whole steps behind boy A, they would still be running in step. Now if the soap-bubble be the thickness of a whole wave of light, the ray which goes to the back surface and returns is still in step with the ray which turned at the front surface, but if the soap-bubble be only as thick as a quarter-wave of light or one and a quarter, the rays would be half a step out on the return journey, and therefore one would interfere with the other and produce darkness. Therefore when it was thinner than the length of a red ray, the red rays would be out of step and could not be seen, whereas the shorter waves, such as blue or violet, would be accommodated, and they would race back in step and therefore be visible. We see (Fig. 33) the course of these rays of light falling on the outside and inside surfaces of a section of a soap-bubble which we have drawn with great exaggeration of its thickness.

Now we come to the beautiful experiment of Newton, by which he was able to measure the exact thickness of each film which produced each tint of colour.

You can try the experiment for yourself.

In window-glass, if you look along the edge, you will see that nearly every pane is slightly curved. In cutting glass a glazier looks along the glass first, and turns it with the concave side upwards, so as to

avoid breaking it by the pressure of his diamond. Take two small pieces of slightly-curved glass, or one curved and the other straight, and press the convex side on the straight side. When you press them together hard with your finger and thumb, you will see round the point of contact beautiful circles of rainbow tints.

In this experiment there is a thin film of trans-

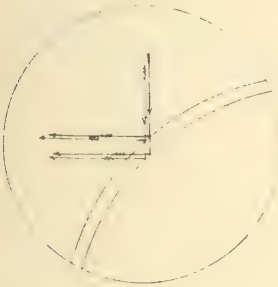

Fig. 33.

Fig. 34.

parent air between the pieces of glass, increasing in thickness outwards from the point of contact.

These are called Newton's rings (Fig. 34). Wherever they show brightness, there the waves are in step, one adding to the amplitude or vertical height of the other. Wherever they are dark or tinted, there the waves have got out of step, and so produce darkness, or they are broken up and show the shorter waves such as green, blue, or violet.

When natural light falls on the glass we see the rainbow tints, but when one light, such as red pass-

ing through a red glass, is used, then the rings are alternately red and black.

Any greasy fluid, such as oil or turpentine, floating upon water becomes a thin film, and reveals colours in the same way as the soap-bubble or the pieces of slightly-curved glass. Newton made a large slight curve touching a plane surface, and by mathematics he calculated the various lengths of the lines joining the two surfaces (Fig. 35). Then comparing them

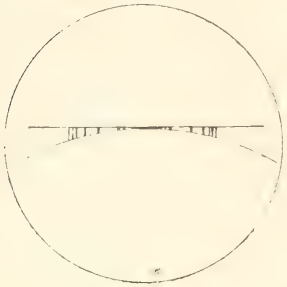

Fig. 35.

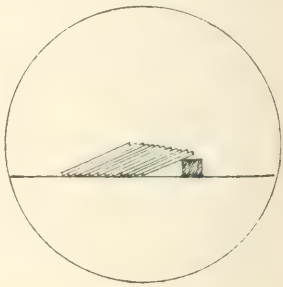

Fig. 36.

with the positions of the various colours which he saw, he determined the length of the waves which formed each colour.

The same principle explains the cause of the beautiful tints which we see on the polished surface of mother-of-pearl, which is formed of very thin transparent plates lying close on one another. When it is examined by a strong magnifying-glass the edges of these plates can be seen, so that it appears like a dozen panes of glass of the same size placed leaning sideways against a support (Fig. 36). The edges

form little steps, and we can see that a ray of light falling on one step, and being reflected, gets the start of another ray which falls on the step just below. The result is that sometimes the waves are reflected in step with one another, and sometimes out of step, causing the same phenomenon of colour which we have observed takes place in the soap-bubble.

That the colour of mother-of-pearl is due to structure alone, and not to any colour in the substance itself, is proved by the fact that if we move it so as to look at it from a different angle, the colour changes. Also from the fact that if we take an impression of it on fine black sealing-wax, the sealing-wax will show similar colours when viewed under a ray of light. In this case it is evident that the various tints cannot belong to the sealing-wax. It is black, and if its surface were scraped so as to remove the polish and leave it dull, every ray would be absorbed, and its colour would be a dull black. They are, therefore, really formed by the irregularity of the start of reflected light from a surface which contains microscopic polished ridges and hollows. This phenomenon is called the colour of striated or scratched surfaces.

Boyle was the first to assert that colour could be formed at the extreme surface of a body, and that it was not necessary to suppose that it came from the inside of the substance. He gave as an instance the colour of a tempered bar of steel which may be either straw-yellow or blue. If the steel were broken across no colour could be detected in the inside.

He also describes an experiment which he made. He melted some pure lead in an iron pot and skimmed its surface. The moment that he did so, the air cooled the new surface and formed the thinnest possible film of hardening lead. Bright colours flashed from this surface, which changed as the film grew thicker.

He skimmed the lead again and again, so long as it was hot enough for the experiment. When he desisted and let it cool until it became hard, the last surface was coloured and those colours remained fixed; but when he scraped the surface, ever so lightly, the colours disappeared, and bright, solid lead was seen beneath.

He had proved that the colours came, not from the lead itself, but from the reflections of the various waves of light from the upper and under sides of a thin film on the surface.

There is still another matter to be discussed.

We have seen that light may be compared to waves which advance along the surface of water. Newton knew this, but he was puzzled how to explain the fact that a ray of light shining on an opaque body caused a sharply-defined shadow to appear behind it.

This light should proceed from a point in order to form a shadow with sharp edges. There was an old-fashioned plan for taking portraits. A single candle was placed on a table, and its light, coming from a point, threw a sharply-defined shadow of the profile of the sitter on a sheet of paper pinned

to the wall. This shadow could then be traced with a pencil. But if a lamp with a large globe were used, the shadow was blurred, and this partial shadow is called a penumbra.

This penumbra is seen when an eclipse takes place, because the sun is so much larger than the earth or the moon (Fig. 37).

The light of the sun is only totally hidden in the

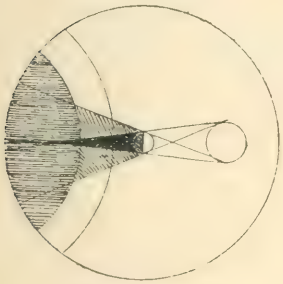

Fig. 37.

Fig. 38.

cone of shadow. It is partly hidden in the space called the penumbra.

The reason is that the waves of light advance in a straight line, and seem to be cut off whenever they strike upon an opaque substance. But if the rays of light are waves, how is it that waves of water can turn round a corner, and that a corner stops the waves of light? Newton was right in arguing that waves of light should bend round a corner, but he did not know sufficiently the law of interference of waves, so that they might be there and yet, by interference with one another, produce darkness.

Let us take an illustration of waves of water changing the direction of their course in passing through the entrance of a harbour. They come through the opening. The centre of the waves go straight on. Those at the sides spread out like a fan to right and left.

Now let us treat the waves of light in the same way, and see how they behave (Fig. 38). Let a ray of light pass through a slit in a piece of cardboard. Opposite the slit hold another sheet of cardboard in which a similar narrow slit has been cut, and look through this second slit. You see the first slit full of clear light, but ranged on either side of it you see other slits, not so bright, shining with rainbow tints. The further they appear from the central slit, the less brilliant is their light. These slits, which appear at either side of the central slit, which is the only real opening, are caused by the waves of light which diverge obliquely from the centre. If the light be natural daylight the side slits appear with the rainbow colours, showing that the waves have got out of step, as in the colours of thin films; but if the light is only one colour, by making it pass, say, through a piece of red glass, the side slits of light are all red, diminishing in brightness, and they are separated by bands of darkness, showing that there the waves of light have completely interfered with one another, so that the light has been extinguished. In making this experiment it is necessary that the light should proceed from a single point, which can be done by concentrating the rays into a point by a lens of short

focus, or by reflecting it from the convex surface of a watch crystal which has been blackened on the inside. If a larger light be used, the phenomenon cannot be seen, as the light-waves, coming from a surface of size, interfere too much with one another.

Beautiful patterns can be made by altering the shape of the opening through which the light passes, making it either a round hole or a long slit like a line, or a square or more squares than one. This behaviour of a ray of light passing through a small opening is called the *diffraction* of light. There are many other phenomena to be considered, which we must defer to another chapter.

III

POLARIZATION AND OTHER PROPERTIES OF LIGHT

MANY earnest efforts were made for a long time by the most patient philosophers to understand the reasons for all the phenomena of light caused by refraction. They wished to discover the relation between the course of a ray of light which falls on the surface of a medium like water, and the course of the same ray when it enters the water. This was discovered at last by Willebrod Snell about the year 1620. He found that if the rate at which a ray of light passes through air was represented by 4, the pace at which it travelled through water was 3. Also that this proportion differs in various fluids and gases; it is called the index of refraction. Another startling discovery was made nearly fifty years later by Erasmus Bartholinus of Copenhagen, when he observed the passage of light through a crystal of Iceland spar.

In order to appreciate the value of this discovery we must understand something about the structure of crystals. We know the shape of a cube, which is the same as dice. If we constructed a skeleton cube

of wire hinged at the corners, so that it could change its shape by pressure, and if we pressed two opposite corners towards each other, we should have in each side a figure called a rhomb, well known as the shape of the figure commonly called a diamond.

The cube thus altered is called a rhombohedron, and this is the shape of a crystal of Iceland spar (Fig. 39). The transparent particles which form this crystal lie in the directions in which it can be split with a knife, which are called the lines of cleavage.

We can observe the formation of crystals such as those of water when frozen into ice, or alum, or sugar known as sugar-candy.

By a fixed law crystals are built up in certain definite directions, just as a bricklayer in building a house places the bricks in definite lines. The secret architectural force at work in the formation of crystals can be best explained by observing the nature of a magnet. When we take a strip of steel and rub it along a magnet, it becomes a magnet itself. If a magnetic needle be brought near to either end of this piece of steel, one end of the needle is attracted by one end of it and repelled by the other.

These ends are called the north and south poles of the magnet. We see them at work in every mariner's compass.

If the magnetized strip of steel be broken in two pieces, each half instantaneously becomes a separate magnet, having two opposite poles in each piece, and

if it were ground into bits as small as dust, each grain of that dust would still be a magnet, and therefore, if free to move, the particles of steel dust would arrange themselves in definite order. It is supposed that some force like this must be at work in compelling the dissolved particles of sugar, when drying, to arrange themselves on a thread in the shape of a crystal of sugar-candy.

As crystals are acted upon by polar force, light

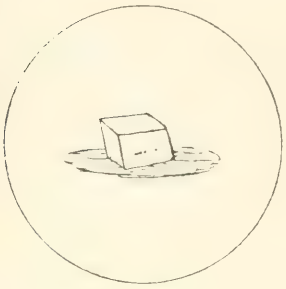

Fig. 39.

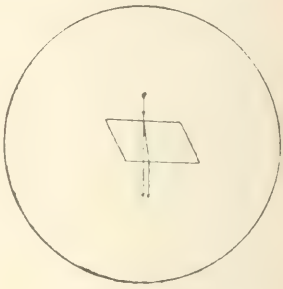

Fig. 40.

affected in a certain way when passing through some of them is said to be polarized, because the ray of light thus treated is found to have two sides, just as every magnet has two ends. To illustrate this property of light, let us take a piece of Iceland spar and place it over a dot of ink. Looking at the dot through the spar, two dots are seen. Or if we paste on one side of the crystal a piece of opaque brown paper, in which a small hole has been pierced, and look at it through the spar while holding it up to the light, we see two holes of equal brilliancy.

The ray of light has been split into two parts. One of the rays is called the ordinary ray, because it obeys the ordinary laws of refraction; the other is called the extraordinary ray, because it behaves in an extraordinary manner.

You observe this when you turn the Iceland spar round, as you would turn a plate on a table. The ordinary ray remains in its place, but the extraordinary ray moves in a circle round it, according to the different positions of the crystal (Fig. 40).

Let us try to understand why this is so. The ether in which the vibrations or waves of light travel must have two qualities—extreme refinement, for it gets inside and penetrates hard substances like glass or diamond; also it must have great elasticity, for light keeps it in constant and rapid vibration.

In open space there is no hindrance to the full development of these qualities, but inside glass or diamond its power to vibrate is, as it were, hampered more or less; more when it vibrates across the grain of the substance, and less when it vibrates with the grain.

For instance, in a slab of ice the crystals lie together, pointing up and down. If we cut out a square inch of ice from a slab an inch thick, we should find that it acted in this way on light, for the light could pass with greater freedom from top to bottom (Fig. 41) than from side to side, for then it would be going through across the grain.

The movements of a natural ray of light when

vibrating may be compared to the swinging motions of a pendulum.

Let us compare the advancing ray to a pendulum which is being let down from the sky to the earth in a vertical line (Fig. 42). We can see that the pendulum may swing from side to side, or from back to front, or in any direction across the line of its downward advance. But when the extraordinary ray passes through a crystal of Iceland spar, it ceases

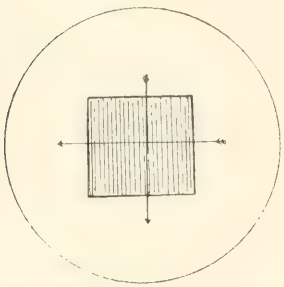

FIG. 41.

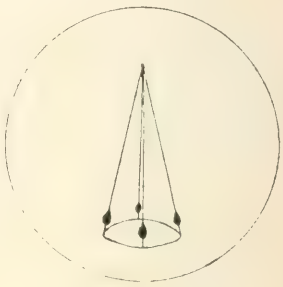

FIG. 42.

to vibrate in all directions, and is confined to one direction. Take two pieces of card and draw on them waves representing the waves of light. Let one lie flat on a table, and hold the other up on its edge. You can see then two series of waves vibrating at right angles to each other. In other words, one series is vibrating in a horizontal plane and the other is vibrating in a vertical plane (Fig. 43). Now a reflected ray changes in some measure its plane of vibration, and therefore these reflected rays are said to be partially polarized.

A good illustration of the motion of a polarized ray of light is the motion of waves on water. The undulations advance towards the shore, but the particles of water in the waves can only move up and down ; they move neither forwards and backwards nor from left to right and right to left. The drops of water form waves by motions up and down across the line of the advance of the waves.

To enable us to observe the behaviour of a polar-

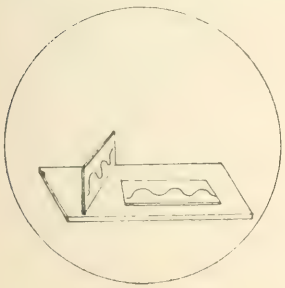

Fig. 43.

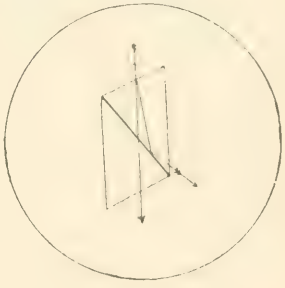

Fig. 44.

ized ray of light, an apparatus was invented by Nicol which could get rid of the ordinary ray and leave the extraordinary ray to be observed by itself. It is called a Nicol prism, and we must pay attention to its structure. He took (Fig. 44) a piece of spar and sawed it across from one obtuse angle to the other. Then he polished the sawn surfaces and cemented them together in the same position by a transparent substance called Canada balsam. This balsam has the property of refracting light somewhat less powerfully than the spar.

Observe the course of a ray of light through this Nicol prism. The ordinary ray strikes the Canada balsam at such a slanting angle that it cannot penetrate it, and therefore it is totally reflected off the surface of the balsam and sent away right out of the prism. Look at the other ray, how it gets through the film of Canada balsam and passes out at the end of the prism totally polarized—that is, vibrating in one transverse direction only.

Having this prism, we possess an instrument by which we can detect whether light is partially polarized or not. For if a Nicol prism be placed in the course of a beam of light, by getting rid of one ray and letting the other through, the light which is being examined appears intense if it passes through with the grain, or feeble if the crystal is turned through a right angle. But it may be asked, What is the use of all this investigation? What is the practical outcome? Even when used as a scientific toy, a Nicol prism attached to a microscope gives an exhibition of the most marvellous displays of colour. As the waves of light interfere with one another, some are extinguished and others are intensified. The reason of this beautiful phenomenon could not be understood unless the laws of polarized light were known. The more we study these laws, the more do we discover infallible proofs that light is caused by waves in the ether, and that colour is revealed by the dispersion and mutual interference of those waves. The ordinary observer may be entertained by a lovely display of colour, but the

thinker rejoices in the knowledge that he has found the key which can unlock the mystery of the phenomenon of light, which is the glory of creation. There is another question which might be asked in vain only for the knowledge which has been thus gained, viz., Why is the sky blue?

To understand the answer to the question we must consider the different colours which appear in various substances according as the light is reflected off them or transmitted through them. When we stand with our back to the sun and see peat-smoke from a cottage curling up through dark trees, that smoke looks blue. An artist in depicting it may use a little of the same blue which he employed in painting the blue sky, viz. cobalt and white. But if we stand nearly facing the sun so that the sunlight shines not on but through the smoke, we observe that its colour is a dusky red.

The smoke looked blue when the rays of light were reflected off the particles of floating carbon of which it was composed, but when they are reflected off a jet of steam escaping from an engine, the steam looks not blue, but white. The reason of the appearance of whiteness in the steam is that the globules of water which form its substance are relatively large, and they therefore reflect whole rays of light which must be white. By the same reasoning we conclude that the smoke looked blue, simply because the particles of carbon were so small that they did not catch and reflect whole rays, but only the small waves of the ray of light, while the

larger waves, not being caught, passed through. But the smaller waves which were reflected are the blue rays, whereas the remainder which passed through are the red waves of the ray of light.

By this observation we make our first step towards answering the question under consideration. By use of the Nicol prism we gain another step. When the light of the blue sky is made to pass through it, it is found to be intense when the prism is in one position and less intense when the position is changed by turning the prism round. Then the great fact is revealed that the light which shines from the blue sky is reflected light and partially polarized. It comes to us by vibrations made at right angles to the direction in which the sunlight is advancing.

Remembering our observation of the peat-smoke, we are forced to the conclusion that the blue colour of the sky is caused by the polarized reflection of light from dust of extreme fineness which floats all through the air. The blue of distant mountains proceeds from the same cause, only that their blue is made pale by the reflection of some whole white rays of light off particles of water-vapour which are floating in the lower parts of the atmosphere near the damp earth. We know, as a fact, that the clearer the air, the deeper is the blue of distant mountains, and when rain is gathering in mist the blue changes to grey. When rain has fallen and brought down all the suspended moisture, the air is cleared and cleaned, and the distant mountains look intensely blue.

Grey is the result of some whole rays of light being reflected from particles of matter large enough to receive them, while many of the rays are absorbed, and the brilliancy of the whole consequently reduced from the lightest grey, approaching white, to the dark black-grey of a foul river when the mud of the bottom is stirred up by a passing steamer.

Having thus found the explanation of the blue colour of the clear sky, how do we account for the gorgeous hues of a yellow or a rosy sunset in a clear sky? How do we account for the red colour of the clouds at sunset or sunrise?

We must remember that the atmosphere is a great gaseous envelope surrounding the round earth (Fig. 45). When the sun is high overhead its rays have to pass through a much shorter space of air than when they touch the circle of the earth as a tangent.

If we look at a part of the sky near the sun when it hangs high in the heavens, the blue is not seen, because the whole rays come through direct to the eye. At some distance from the sun we see the polarized rays reflected at an angle from the very fine dust suspended in the air. But when the rays come along at sunset through a great thickness of air, the tiny blue rays are caught on the particles of fine dust and reflected off at various angles and never reach the eye. But the yellow and red rays are too large to be caught by the dust, and they come through to the eye.

Further, they pass on to the opposite horizon, and any clouds placed there or elsewhere are seen to be

yellow, pink, or red, because these are the only rays which reach them, the blue having been caught and intercepted.

Some years ago a great mass of fine dust was hurled into the highest parts of the air by the explosion of the volcano Krakatoa. This dust floated all round the earth, carried in suspension by the currents or winds of the upper atmosphere. When the dust reached the British Isles all the usual effects of rosy sunsets were exaggerated in a wonderful degree; the fact being that this dust formed an obstruction through which only the yellow, the orange and red rays could pass.

These exhibitions of gorgeous colour lasted until the dust was drawn gradually to the earth by the force of gravitation, and then the air was restored to its natural condition.

As in the case of the investigation of the colours of the rainbow we saw that all the theories could be proved correct by making an artificial rainbow, which was done by causing a beam of light to fall on a globe of glass filled with water, which represented a round drop of water held stationary in position, even so the theory of the cause of the colour of the blue sky can be tested by the experiment of making artificial blue sky.

Professor Tyndall describes this experiment which he made when delivering his lectures on light in America. The apparatus used was a glass tube about a yard in length and from $2\frac{1}{2}$ to 3 inches internal diameter. The gas or vapour to be examined was

introduced into this tube, and a condensed beam of light from an electric lamp was brought to bear upon it.

The vapour [1] was so chosen that one of its properties was that as soon as the light shone on it, some of its particles were decomposed by the light, and precipitated or turned into solid particles of extreme fineness. He was able by regulating the amount of vapour to graduate the size of the particles to any degree of fineness, forming some which could be seen by the naked eye, or others so small that the most powerful microscope could not detect them. These were as small as a fraction of the length of a blue or violet wave of light.

The result was the formation in the tube of a blue cloud.

This cloud was invisible in ordinary daylight. To be seen it must be surrounded by darkness, while it only is illuminated by a powerful beam of light.

When the particles were growing larger by the introduction of more vapour, the appearance of the tube was a splendid azure blue, which rivalled the blue of the Italian skies. As they increased in size they became whitish, and, finally, when large enough to reflect a whole ray, they shone with white light, like an ordinary bright cloud on a summer day.

When the Nicol prism was applied to this artificially-made blue sky, it was found that the light shone from it at right angles to the direction of the

[1] Composed of nitrate of butyl vapour mixed with air and hydrochloric acid in certain proportions.

beam of light which fell upon it, and that it was, therefore, perfectly polarized.

Thus the cause of the colour of the blue sky was absolutely proved by a test experiment. It was found to be made by polarized light.

We have seen already that in the phenomenon of colour some rays of light are absorbed and others reflected. An interesting question now arises, viz., What becomes of the rays which are absorbed and are consequently lost to sight ? Are they lost, or are they simply changed into other forms of force ? There is a great law of nature called the conservation of energy. By this law motion is changed into heat and heat into motion. For instance, in the docks there are great machines used for cutting steel plates, for punching holes in them, and for enlarging holes.

Great force is necessary in carrying out these operations. When the puncher punches out a hole the little disk of steel becomes immediately so hot that it can scarcely be handled. The hard steel bit used for enlarging holes would soon be red-hot when working only for a contrivance by which a stream of water is kept pouring on it to cool it. The moment it begins to revolve and shave off strips of steel from the sides of the hole,the developed heat is manifested by the steam which rises from the stream of water.

The same law applies to the absorption of the rays of light. In being absorbed they are converted into heat or other energy, and thus are not lost.

A simple experiment shows us how they are changed. The bark of the horse-chestnut tree contains a substance called Æsculin. If we make a solution by soaking the bark in water, and fill a glass vessel with it, we can then concentrate a beam of light on the bottle by means of a lens (Fig. 46). Immediately we observe that where the light passes through the fluid, a beautiful cone of blue light is seen, which shines in every direction. We wish to

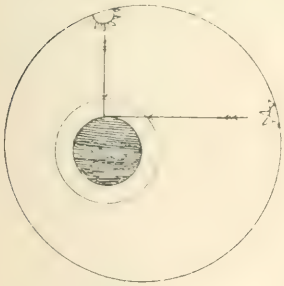

FIG. 45.

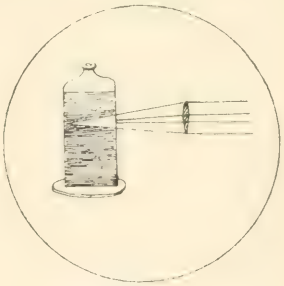

FIG. 46.

know the cause of this blue light. Let us make the ray of light first pass through a flat bottle of the same solution, and we find that the blue light can hardly be seen (Fig. 47). Our conclusion must be that this blue light comes from the rays which were absorbed from the ray of ordinary light, for when these were first sifted out by the flat bottle of solution, there were none left to shine in the cone of light.

The same power of changing the absorbed rays was found by Professor Stokes to exist in a crystal

called Fluor spar, and therefore he called the phenomenon Fluorescence. The next thing to be found out was, To what part of the spectrum band of colours did these rays belong ? When the light was examined it was seen that the rays were so far bent out of their course that they appeared beyond the violet rays which were the most refracted rays visible to the eye.

We have said that Fraunhofer numbered the dark

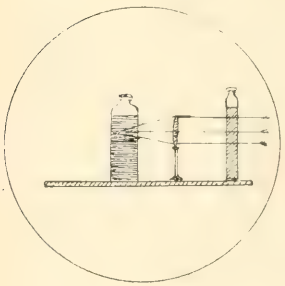

Fig. 47.

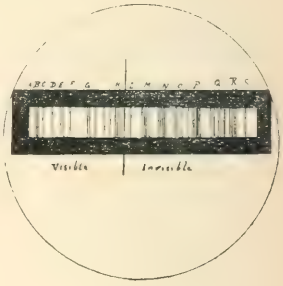

Fig. 48.

lines of the solar spectrum by the letters of the alphabet. Lines A to C appeared in the red, D in the yellow, F just between the green and the blue, marking approximately the middle of the visible band of light. G appeared in the indigo, and H in the violet. This was the limit of human sight. But the new rays of Fluorescence stretched away to the right, and had to be numbered L, M, N, O, P, Q, R and S. These are the famous ultra violet rays, the vibrations of which are so intensely rapid that they cannot be

perceived by the human eye. Not that they are in themselves invisible, but the light shining from them is so refined that it is overpowered by the light of the ordinary violet rays (Fig. 48).

There are other substances besides Fluor spar and Æsculin which have this property of exhibiting beautiful blue rays of light, although when looked at from another aspect they do not appear to be blue. For instance, if you look down on petroleum oil in a jug, it appears to be a pale straw-yellow, but when you pour it into the oil-hole of a lamp in a narrow stream, it flashes with intense blue colour.

Another substance is a solution of quinine, colourless in itself, but capable of exhibiting these extra rays. If we paint a flower with this clear solution on paper and let it dry, we see nothing, but if we place it under the violet rays of the spectrum, it shines out with brilliance. By the use of these substances the ultra violet rays are rendered clearly visible. Even if we could not see them, photography would reveal their existence. When the spectrum band is photographed it is found that no picture is formed of the deep red rays, a slight effect is made by the yellow and green, and the blue and violet rays are by far the most powerful. But the rays beyond the violet are also strongly photographed, and show white in the photographic print. The rays towards the red end of the spectrum are therefore called non-actinic, and those towards the violet end are called actinic. The photographer's so-called dark room is not dark at all, but the light in

it is red, and being red, it has no power to decompose the salts of silver which form the foundation of a sensitive photographic plate. The least blue light admitted to that room would destroy the picture on the plate, for it would decompose the whole of it, making it opaque throughout.

The actinic rays of light are very powerful in their action. A Swiss tourist walking on snow in the sunshine is attacked by these rays, and he comes home with his face a mass of blisters and sunburn. Had his face been covered with a red mask, none of these effects would appear.

Dr. Lommel mentions an experiment by which the power of actinic light is shown.

A mixture of equal parts of chlorine and hydrogen is introduced into a thin glass ball. If this be exposed to the daylight the two gases gradually combine to form hydrochloric acid gas, commonly known in water solution as muriatic acid.

But if the light of a magnesian lamp, which contains a large proportion of the actinic rays, be allowed to fall on the glass ball, it breaks instantly with a loud report. The light causes such a rapid chemical combination of the two gases, and so much heat as they rush together, that the glass ball is shattered.

If a piece of yellow glass were placed between the magnesian lamp and the glass globe no effect would be seen, but if the yellow glass were removed for a moment, the glass globe would break.

One more phenomenon connected with the ab-

sorbed rays must be mentioned, viz., the property of some substances to give out again light which they have absorbed. This is called phosphorescence, a name given because it resembles the gleaming of phosphorus in the dark, which, however, is a real combustion, and in no way to be identified with this matter of the storage of light.

It is known that when a diamond is placed in sunshine it continues to gleam after it has been brought into a dark room. However, a less expensive article of this sort may be obtained and examined by all. On some match-box cases we see that one side, usually the top, is painted white or nearly white. This is luminous paint, which has the property of storing up the sunshine of the day, and giving out a sufficient gleam during the next night by which we can find the match-box in the dark.

The basis of this paint is a sulphur compound of calcium. If the paint be left covered during the day with red or yellow glass, it stores no light, but if it be exposed to the light of a burning tape of magnesium for a few seconds, then in the dark it gives out a soft light.

This fact proves that the actinic rays only are the cause of phosphorescence.

To these powerful little waves of light we owe the bleaching of our linen and the fading of our carpets and dresses. They permanently alter the chemical composition of the materials, which were originally able to absorb some rays of light and reject others, thus making their peculiar colour.

We come now to think of some great discoveries, which have been made by means of the knowledge of the laws of light.

It was known that certain metals, when fused and converted into vapour by the heat of a Bunsen burner, showed different colours in the flame. For instance, sodium chloride, which is common salt, gave a yellow flame; the salts of two rare metals, lithium and strontium, make a red flame. Potash flame is violet and the flame of barium is green.

Bunsen and Kirchhoff, the great founders of the science of analysis of substances by means of the spectrum, called spectrum analysis, examined these and many other substances by looking at their flames through a spectroscope, which was composed of a series of prisms, so that the light, being dispersed into a long band, was clear, for the colours did not overlap as they do in the rainbow. Kirchhoff found that these spectrum bands of colour differed widely from the spectrum formed by ordinary sunlight. We have seen that it consisted of a continuous band of coloured light containing all possible shades or hues, from deep red to extreme violet, and that this band was crossed by numerous dark lines. To illustrate the appearance of these lines, let us suppose a pattern made by very fine threads of silk placed closely side by side, and corresponding in tints to the various colours of the rainbow. We have then an imitation of a piece of a very broad rainbow made in separate silk threads. Now let us carefully cut out a few single threads from each colour, and we

have a representation of the dark lines of the solar spectrum. Especially let us select two threads from the yellow and cut them out, then leave one thread and then pick out the next, and we have a representation of the thick and thin double line numbered D, which reveals the presence of sodium, the basis of salt, in the flame under examination (Fig. 49). This line appears in nearly every spectrum band, because it is almost impossible to get rid of salt from any substance. The ocean extends over by far the greater portion of the earth's surface. The winds and storms blow fine spray into the air. Each globule of spray contains salt, and when these dry by evaporation, the most minute dust of salt is carried everywhere through the air. If a Bunsen burner, such as the ordinary blue flame of a gas cooking-stove, be placed on the floor, and you stamp on the carpet near it, immediately the flame shows a yellow tint. This is caused by the combustion of salt dust, which is found in every dust.

Now the main difference between the spectrum band of a burning metal and the spectrum of the sun is that whereas the sun spectrum shows a band of light crossed by dark lines, the spectrum of burning metal vapour reveals a dark background crossed by bright lines of colour. For instance, the spectrum of sodium is a dark background crossed by a bright double line at D, and if, by a suitable apparatus invented by Bunsen, the solar spectrum and the sodium spectrum be placed so as to be seen the one directly over the other, then it is found that the dark line D

in the solar spectrum stands exactly in line with the bright line D in the sodium spectrum (Fig. 50). The same fact was observed on comparing the spectra of all vaporized metals with the spectrum of the sun. Wherever they made a bright line, a dark line appeared in the solar spectrum exactly in the same position. Kirchhoff meditated long on this discovery, until at last he groped his way by a series of patient experiments to the full and satisfactory solution of

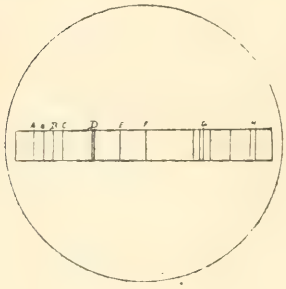

Fig. 49.

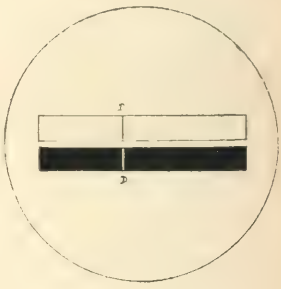

Fig. 50.

the mystery, and in doing so he opened up the way to the most important and astonishing discoveries of modern times.

The analysis of metals by observing their spectra was found to be of extreme delicacy and accuracy. The spectrum revealed differences which could not be seen by the naked eye.

For instance, both lithium and strontium give out red flames of apparently the same tint, but when examined by the spectrum their bright lines were

wholly different the one from the other both in number and position (Fig. 51).

By this means every metal could be made to reveal its individuality.

The next step was to distinguish between the peculiar light given out by each flame and that absorbed by the same. A simple experiment proves that all light does not pass freely through a flame. If a candle be held between a bright gas-jet and a

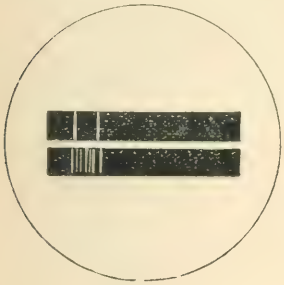

FIG. 51.

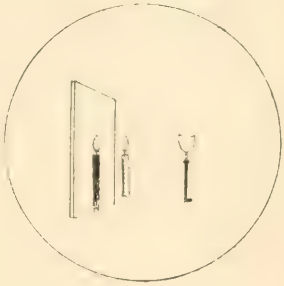

FIG. 52.

wall, a faint shadow of the candle-flame is thrown on the wall, showing that it absorbed some of the rays of the gas-jet and let others through, while the candle itself made a black shadow, because, being opaque, it absorbed or extinguished all the rays or reflected them back, which produced the same result (Fig. 52).

Now when light was sent through a flame it was found that exactly those rays which were natural to the flame were blocked, while all other rays were given a free passage through.

For instance, when light was passed through the yellow flame of sodium, the yellow rays were stopped, but it was transparent to the red, the green, the blue, and the violet.

Of course a necessary condition for this experiment is that the light which was made to shine through the flame should be brighter and more intense than the flame itself.

If the yellow line from the sodium-flame were brighter than the yellow rays in the other light, no absorption would be perceptible.

The principle involved in this experiment was applied to an examination of the sun.

According to the law of all solid bodies glowing with heat throughout their substance, the inside must be hotter than the outside, because the outside is constantly radiating its heat away into space. It is known that the heat of the sun is caused by the force of gravitation acting on the whole mass and converting the motion of contraction into heat.[1] The sun is surrounded on all sides by the extreme cold of interstellar space, and therefore its surface is continually parting with enormous quantities of heat.

When we look at the surface of the sun shining with dazzling light we may know that that surface has a background vastly hotter than itself. The inside of the sun acts, therefore, towards the surface as the intensely hot limelight acts towards the feeble flame glowing with vaporized sodium.

[1] This is now thought to be only a partial cause since the discovery of the radio-active bodies.

The surface of the sun's atmosphere is a mass of the vapour of various metals heated to such an extent that they float on it as white-hot clouds. If one of these clouds contain any sodium in vapour it will stop the peculiar yellow of sodium-flame coming from the body of the sun itself, and when the light is examined in the spectrum the stoppage of light is revealed by the dark double line D. By this means it was discovered that the metal sodium, the basis of salt, exists in the material of the sun.

It reveals itself whether the light come direct from the sun or by reflection from the moon or the planets. The intensity of light differs, but the dark lines of the solar spectrum are always found in their proper places, because the special tints have been stopped out when the light started on its journey. By the same tests various other metals were found to form part of the sun's material, and it is known that it contains vast quantities of iron.

Once this principle of investigation was established, further discoveries were made by it which long ago would have seemed to be incredible.

How little could our forefathers have imagined that the day would come when men should be able to say that they knew a good deal about the materials out of which the stars were made, although their distance was so great that no man could calculate it. Yet all this marvellous knowledge has come to us through the spectrum.

It is now known that most of the fixed stars contain in various proportions the very same materials

which are found in our sun and in this earth. Round our sun, during the time of a total eclipse, certain protuberances were seen like vast red flames many thousands of miles in height (Fig. 53). The spectrum revealed that these were great masses of glowing hydrogen, the gas which in chemical combination with oxygen forms water. Stars like Sirius, the bright dog-star, are now known to possess an incalculable amount of this gas hydrogen, glowing with intense heat at their surfaces.

The spectroscope was turned on the light of those faint patches of misty light, known as nebulæ, seen in the heavens by powerful telescopes, and at once the answer was given to the question, Are they very distant stars or are they masses of glowing gas? Some were found to be drawn together in points, making new suns, others were discovered to be only gas in which no concentration has taken place as yet.

Although so many of our known metals and gases have been found to exist in these remotely distant objects, yet it has happened that the spectrum of their light revealed lines which did not correspond to the lines of any known earthly substance. This fact need not surprise us, for the spectrum has shown that there are many substances in this earth which no man has yet seen.[1]

Whenever Bunsen and Kirchhoff discovered a spectrum containing lines which did not belong to

[1] In some of the Nebulæ a substance which gives light has been detected which as yet is not found elsewhere. Hence it is called Nebulium.

any known substance, they concluded that they proceeded from a substance as yet unknown. They were investigating the properties of a certain German mineral water. They evaporated great quantities of it until they obtained a small amount of solid residue. They vaporized this and sent its light through the spectroscope, and then discovered that it was an unknown mineral, because its lines did not agree with the position of the lines of any known matter in the earth. They called the newly-found metal Rubidium. In the same way they discovered another and called it Cæsium. Shortly afterwards Mr. Crookes discovered Thallium.

No limit can be placed on the amount of new knowledge which may come to mankind through the investigation of the complex laws and operation of light, but what we have already discovered shows that the whole subject is one of inestimable value and of absorbing interest.

Not only has the examination of light told us about the materials of the sun and the distant stars, and nebulæ and comets, but it has answered another question which might well be thought to be unanswerable. It is a sublime speculation—Is the sun stationary, or is it with our world and all the planets drifting through space, and if so, in what direction are we going, and at about what pace are we travelling?

Surely a more audacious question was never proposed to the mind of man to solve, and yet it has been solved and answered by light, and by light

alone. It could only be answered by light, for light is the sole medium by which we have any knowledge of the sun, the planets, the stars, and all the heavenly bodies.

They shine either as luminous or illuminated bodies, and they speak to us in the language of light.

If we were at sea approaching the mouth of a harbour, and if on each harbour pier there was a lighthouse, we should observe that when we were at a great distance the harbour lights seemed to be close togther, as we drew nearer they seemed to separate out gradually, and as we entered the harbour one light would stand on the right hand and the other directly opposite on the left.

But when we passed them the reverse process would take place. At first they would appear far apart, but as we went on into the harbour they would seem to come close together again.

Now if the sun and planets be moving in a great circuit through space, there must be stars in front of us which we are approaching, stars behind us from which we are retreating, and stars on each side of us which we are passing.

Those in front ought to appear separating out from one another, and those behind drawing in together.

The extreme distance of the stars renders these measurements so minute that they can only be made with great difficulty; just as if when the ship was two miles from the harbour when the first measurement of the apparent distance between the lights

was taken, and the second measurement was made when the ship approached one yard nearer.

However, astronomers tell us that in the lapse of years the apparent distances between the stars are changing a little, and the changes are exactly those which this illustration of the harbour lights would lead us to expect. The stars in the neighbourhood of the constellation Hercules are opening out, and those in the opposite neighbourhood of Sirius are drawing together.[1]

These facts are corroborated by another method of investigation. The light shining from the stars has been caused to pass through a prism, and thus it is dispersed into a band of colour crossed by Fraunhofer's dark lines. We know that these colours are caused by waves, and we may compare them to other waves formed in the air which reveal themselves in sound. Now the pitch of any note, be it high or low, depends on the number of waves which strike the ear in a second. The lowest note which can be heard as a musical note is that proceeding from an organ-pipe 32 feet long. It makes 16 vibrations in a second. The octave above makes exactly double the number, viz. 32.

The shorter the waves the higher the note, the longer the waves the lower or deeper is the note. If a boat be rowed on a rippled lake it is obvious that when the motion is against the ripple, a greater number of wavelets beat on the bow of the boat per

[1] Hercules is now largely regarded as the apex of the Sun's way.

second than if the boat were at rest, and if it be rowed with the ripple, the waves which it overtakes will be fewer in number.

Let us use this illustration in investigating a sound which proceeds from the whistle of a railway engine. If we and the engine are stationary the whistle has a steady, definite pitch of tone.

But if we are in a train approaching on a double line another train whose engine is whistling, we do

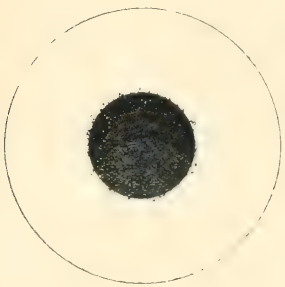

Fig. 53.

Fig. 54.

not hear its true note. The waves of sound being shortened considerably by the rapid approach of both trains, the note sounds higher than it really is. But the moment the trains pass the waves of sound are lengthened out by the retreating motion of both trains, so that the tone of the whistle immediately drops to a lower tone (Fig. 54).

We heard when approaching the note E, and when retreating the note C, whereas the real note sounded by the engine all the time was D. When

the spectrum of the stars is examined, the following remarkable fact is observed. In looking at the stars towards which the whole solar system is advancing, the dark lines of the spectrum are shifted slightly towards the violet end, where the light-waves are shorter, and when looking at the spectrum of the stars from which we are retreating, the dark lines are slightly shifted towards the red end, where the waves are longer. But when the spectrum of stars which are placed sideways to us is examined the dark lines appear in their natural places. By carefully measuring the amount of the displacement of the lines, astronomers have been able to estimate the number of miles per second at which the whole solar system is gliding through space. Nay, more, they have foretold the changes which must take place in the appearance of the constellations such as "the Great Bear" in the next 10,000 years, for the spectrum has revealed the direction in which and the rate at which the individual stars in that constellation are travelling.

Such are some of the marvellous questions to which light has given a satisfactory answer.

IV

THE EYE AND VISION

THE eye is the organ of vision by which all the beauty of light and colour is revealed to us. If we had no eyes, we might know something about the benefits derived from light in giving us warmth and food and rain, and therefore fresh water stored up in lakes and springs, but we could know nothing of the cause of all these things, viz., light itself.

However the eye attained its marvellous powers, whether by slow evolution or otherwise, the examination of its structure and functions must impress the student with the fact that the various processes which led to its present form were the result of supreme intelligence superintending and designing every change which caused its improvement. This is an inference, and we can decide, when we examine facts, whether it be reasonable or not.

First let us think of the arrangements made for its comfort and protection. If a watchmaker made the delicate works of a watch, but forgot to make the case, the practical use of the watch would be nothing, for it would stop the moment we placed it

in our pocket. The eye, far more delicate and susceptible of injury than a watch, had to be protected, although exposed to blows, and wind, and dust, and the drying effect of the open air. So it was placed in a strong hollow of bone shaped like a cup, with a very strong rim. Many a boy when boxing gets a hard blow on the rim of this cup, and though the flesh all round may be so bruised as to form what is called a black eye, the eye itself is kept safe in the cup, resting on an elastic cushion of fat which saves it from concussion. Above the eye is placed the eyebrow, which, like a projecting thatched roof, causes the sweat streaming down from the forehead to fall off in drops and leave the eye clear. The lids are furnished with an apparatus of muscles and nerves by which when any injurious substance approaches the eye, they close immediately, without waiting for the direction of the will.

The tear-gland is placed near the outside corner of the eye. It secretes salt water which gently flows over the surface of the eye and keeps it always moist and clean. If we open our eyes under fresh water we feel a smart, but when bathing in the sea the salt water does not smart, because the eye is accustomed to the salt water proceeding from the tear-gland. When dust enters the eye this gland answers to the irritation, and pours out more water to cleanse away the dust, and the surplus quantity is carried away by a duct which goes from the inner corner of the eye into the nostril.

Then the eyelashes form a delicate fringe above

and below, by which particles of flying dust are intercepted and kept out, and finally there are nerves both in the surface of the eye and in the eyelids, so very sensitive that when any injurious object, such as a fly or bit of coal dust, does get in, they warn us by sharp pain to stop every business we may be engaged in and attend to the eye until it is cleared and at rest. That pain caused by a mote in the eye is a most valuable provision made entirely for our advantage.

Wonderful as these arrangements are, they are as simple, when compared to the eye itself, as the leather case and strap are when compared to the field-glass which they preserve from loss and injury.

The outside coat of the eyeball is called the sclerotic. It is a tough, opaque coat known as the white of the eye. It extends all round except in front, where the transparent cornea is placed. This is the transparent membrane through which we see the iris or circular coloured substance which gives colour to the eye. In some it is light-blue, in others dark-grey or brown ; in novels it is usually supposed to be violet. In the centre of the iris there is a circular opening called the pupil, and it is through this hole that light enters the eye.

The iris acts so as to regulate the amount of light to be admitted (Fig. 55).

If you keep a candle out of sight and look at your eye in a mirror you may see that the pupil of the eye is large, and the iris has retreated so as to form only a thin circle of colour round the pupil, but when

you bring the candle forward between the eye and the mirror, immediately the iris is seen to enlarge so as to contract the size of the pupil and admit less light. When going out of a well-lighted room into the dark we cannot see until the iris has had time to retreat and enlarge the pupil. Also when we pass from darkness into brilliant light we are dazzled until the iris has had time to come forward and regulate the amount of light needed for clear vision.

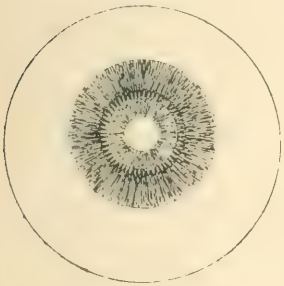

FIG. 55.

FIG. 56.

Just behind the iris is placed the crystalline lens, which, like the object glass in a telescope, causes the rays of light to be focused on the back part of the eye where the retina is placed. The inside of the eye is filled in front with watery and in the centre with vitreous or jelly-like fluid, through which the rays of light pass, and by which the eyeball is kept distended and round (Fig. 56).

So far we can see that a photographic camera has been constructed in imitation of the general

principle adopted in the formation of the eye (Fig. 57). In front of the camera there is the lens. A diaphragm or iris is placed either before or behind, by which the amount of light entering is regulated. If the light be bright, the photographer uses a diaphragm with a small hole ; if it be feeble, the hole is enlarged so as to admit as much light as possible. The rays of light passing through the lens are refracted or bent so as to meet in a point called the focus, and this focus of each part of the picture falls on the screen of ground glass, where it can be seen by the photographer when he puts his head under the black cloth. If it is not focused correctly he uses a screw by which the lens is moved backwards or forwards until the proper focus is arrived at. For a near object, the distance between the lens and the screen must be increased; for a distant object, the lens and the screen must be made to approach one another.

So at last, with all this contrivance and design, the picture is seen clearly defined on the ground glass, and then the sensitive plate can be introduced on exactly the same plane.

Now it would be very awkward if, when we wanted to look one moment at a near object and the next at a distant object, we had to work a screw projecting from the side of the eye so as to alter the focus. But in the eye a much better plan has been contrived. The lens in the camera is of hard glass which cannot change its shape, but the lens in the eye, although beautifully transparent, is so

elastic that certain muscles, called the ciliary muscles, can change its shape in a moment, and make it more or less convex. It is well known that as people grow old, no matter how good their sight has been in youth, a change takes place when middle age is reached. The first symptom of the change is a tendency to hold a book further from the eye. *Punch* represents a middle-aged man holding a book as far from his eyes as his arms can reach. He says, "There is nothing wrong with my eyes, but my arms are too short." His sight was as clear as ever when he looked at distant objects, but print held in the hand was blurred—that is, it was out of focus. The reason is, that as age advances the lens becomes less elastic, and the ciliary muscles, which alter its shape, become more or less feeble. This alteration of focus in the eye is called *accommodation*.

This fact can be proved in more ways than one.

In a certain disease called cataract the crystalline lens becomes gradually opaque, sight becomes at first dim, and then it is lost altogether. The remedy is to remove the lens, which has become not only useless, but an actual obstruction to the entrance of light. When the surgeon has taken it out, light re-enters the eye, but it makes no distinct image on the retina. The person operated on is therefore given spectacles with convex lenses, but he has to get two pairs of spectacles, one for viewing distant objects, and the other for reading or looking at near objects. The spectacles for distant objects have

generally ten units of convexity, and those for near objects have glasses of fifteen units of curve.

The natural eye, by muscular action, changes the convexity of the crystalline lens from ten units when at rest to fifteen when looking at near objects.

In old age the lens lies, as in youth, at a focus suitable for distant objects, hence no effort is needed to see them distinctly ; for near objects the eye is

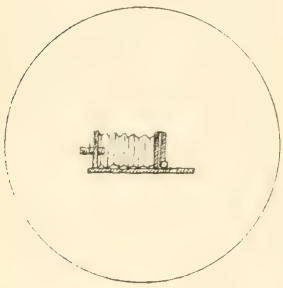

FIG. 57.

FIG. 58.

helped to accommodate vision by a pair of spectacles of slight curvature.

But the alteration of the shape of the lens in the eye can be observed in actual working by the following experiment, mentioned in *Kirke's Physiology*.

If a lighted candle be held a little to one side of the eye, and the observer looks at the eye from the other side, he sees there reflected images of the candle: one, the brightest, from the outside surface of the cornea of the eye, the second from the outside surface of the lens, and the third from the concave inside

surface of the lens. This image appears reversed or upside down, and it is much smaller and dimmer than the other two (Fig. 58). Now if the person whose eye is being observed is told to look at a near object, the second image is reduced in size; it becomes brighter and approaches the first image owing to the change in the curvature of the lens. The images all go back to their former position if the person be asked to look again at a distant object.

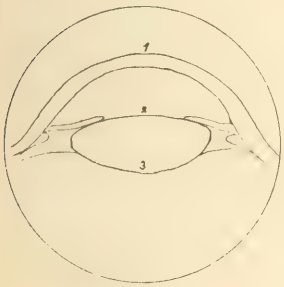

FIG. 59.

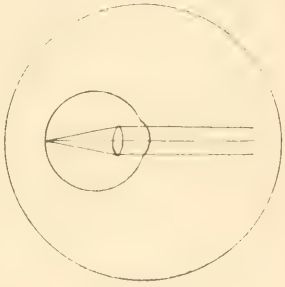

FIG. 60.

The next figure shows the three surfaces from which the images of the candle-flame were reflected (Fig. 59). Before leaving the subject of spectacles we must understand the causes of long sight and short sight. Let us look at diagrams representing various sorts of eyes. First, the natural eye as it ought to be (Fig. 60). You see how the rays of light which approached the eye in parallel lines are first refracted on passing through the cornea, and then refracted still more when passing through the

lens, so that all may meet in a sharp pencil of rays on the surface of the retina. Now when an object is near, the rays do not approach the eye in parallel lines, but as it were from a point smaller than the pupil of the eye.

Hence they incline to come to a focus not on the back of the eye, but behind it (Fig. 61). This focus must be shortened by increasing the convexity of the lens; this process is shown in the figure by

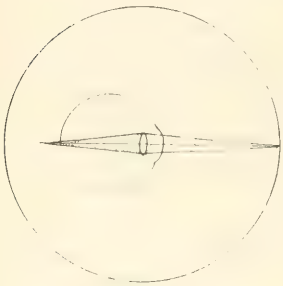

FIG. 61.

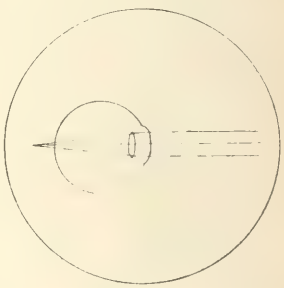

FIG. 62.

dotted lines, the result being that the image is focused distinctly on the retina. The next sort is the long-sighted eye, in which the eyeball is not deep enough, and in which the focus would always be behind the retina. For such an eye weak spectacles are needed for distant objects and strongly-curved spectacles for near objects (Fig. 62).

The third sort is the short-sighted eye, in which usually the cornea is too much curved, so that the focus is made too short inside the eye, and fails to

fall on the retina. Fig. 63 represents a short-sighted eye looking at a near object, which can be seen distinctly because the focus is on the retina. Fig. 64 represents the short-sighted eye looking at a distant object, which appears blurred. The defect is remedied by placing a double concave spectacle glass before the eye, the effect of which is shown, making the focus correct.

As the focus of the short-sighted eye when at rest

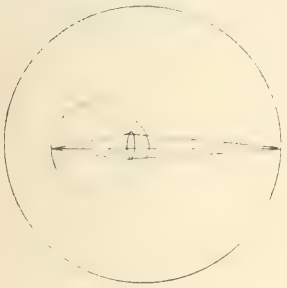

Fig. 63.

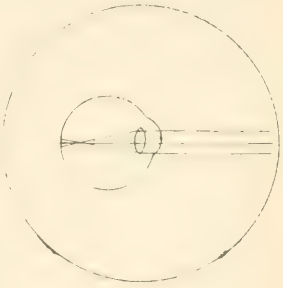

Fig. 64.

is for near objects, such persons can read small print when they are old without spectacles, just as the perfect eye can see distant objects at any age, because when at rest it lies focused for the distance.

Having thus considered the entrance of rays of light into the eye, we consider next the retina on which they are focused.

The thickness of the retina may be compared to a piece of tissue-paper, such as milliners use in packing ladies' hats in a box. It is not nearly so thick as ordinary note-paper. Yet the microscope reveals

the fact that this thin paper-like substance is composed of no less than seven distinct layers. They are formed of very minute nerve ends and cells, and they are really expansions of the optic nerve, which is an outgrowth from the brain.

The rays of light have to pass through these fine nerve layers until they reach a peculiar layer composed of rods and cones (Fig. 65), which is the sensitive part of the retina.

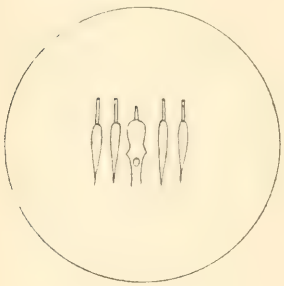

FIG. 65.

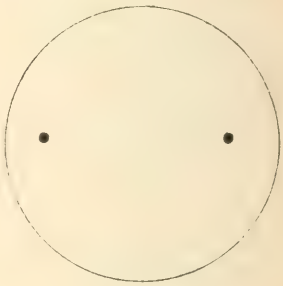

FIG. 66.

On the surface of the retina there are two spots. One, the blind spot, through which the optic nerve and the blood-vessels pass, which spread like a network over the retina. The other, the yellow spot, which lies opposite the line of sight and is the point of keenest vision. Few people know that they have a blind spot in each eye. You can prove it for yourself (Fig. 66).[1] Close the left eye and look at the spot to the left at an ordinary distance. Although you

[1] Make two large dots on paper two inches apart.

are looking at the left spot you can perceive that there is a spot to the right. Now bring the page closer and closer to the right eye. At a certain distance the spot to the right will disappear, because the image of it formed on the retina is then falling on the blind spot of the right eye. Now close the right eye and look with the left eye at the spot to the right, and on bringing the page up to the left eye, the spot to the left will disappear. This blind spot is placed on one side of the yellow spot, so as not to interfere with clear vision. If both eyes be kept open, both spots will appear, no matter at what distance the page is held from the eyes, for one eye will see what the other misses.

At this blind spot the optic nerve passes from the surface of the retina towards the brain. Through the same point the blood-vessels pass and are radiated all over the back of the eye, by which means the organ is renewed by nourishment; but the yellow spot is nearly clear of blood-vessels, and it is the spot on which the focus of the rays of light entering the eye is formed.

The optic nerve is in itself a marvellous structure. A hank of fine fishing-gut may contain about three dozen strands, and it is as thick as a pencil. How many strands of fibres are in the optic nerve, which is a little smaller? Just about 500,000! These convey sensations from the retina to the brain, by which we perceive colour and form. How these are perceived is a question so difficult that it can be only partly answered.

The perception of colour has been supposed to be in some way connected with the layer containing the rods and cones.

We have seen in the chapter on colour [1] that when coloured light is analyzed the various tints have been found to consist of various combinations of three primary colours, red, green and violet. It is thought that certain rods and cones are affected chiefly by the red waves of light, but also in a lesser degree by the green and the violet ; that others are affected primarily by the green, and more or less by the red and violet; while a third set are affected mostly by the violet, and but little by the red and the green.

As an illustration let us construct three waves of light, showing by their heights the position in which they are strongest. We see that a large portion of one wave corresponds to the position of small portions of the other waves (Fig. 67). The result would be various combinations in varying proportions of the three waves. The vertical lines represent the positions in which the various colours would appear in the spectrum.

But no matter how man may understand the structure of the organ of sight, there is a great gulf fixed between all such knowledge and the actual sensation of sight, which must remain one of the inscrutable secrets of Creation. It is certain that all men have not the same perception of colour, for some are known to be colour-blind in various degrees.

[1] P. 46. Young-Helmholtz theory.

Men have been examined carefully, and some have been found who could distinguish between red and violet, the extreme colours of the visible spectrum, but to them the intermediate tints, yellow, green and blue, appeared to be grey. Such persons were unable to distinguish by sight a half-sovereign and a sixpence.

Hering's theory of colour vision is that there are certain substances in the retina affected by three pairs of complemental colours, viz., white and black, red and green, and yellow and blue. Each of the substances corresponding to a pair of colours is capable of two changes, which we may describe as breaking down and building up, which produce one or other colour.

For instance, the red rays of the spectrum are supposed to produce changes in the red-green substance only, and then red is perceived; blue rays produce changes in the yellow-blue substances, but do not affect the red-green substance.

The fatiguing colours which break down the substances in the retina are white, red and yellow. The resting colours which build them up are black, green and blue.

In nature these latter colours prevail, by which the eye is, so to speak, built up and strengthened by rest. The black night, the green fields, and the blue sky are all restful, while we are easily fatigued by gazing at white snow, red cloth, or a large surface of yellow.

In an article in *The Nineteenth Century*, October

1877, Mr. Gladstone discussed the colour sense of Homer. He said that in describing colour he only used two epithets, eruthros and xanthos. Mr. Gladstone interpreted the word "ioeides," violet-coloured, as a term meaning dark.

Homer certainly uses one word where we would use many. He calls the sea violet, and applies the same term to iron and also wool, probably dyed purple. If the word "porphureos" means violet, Homer applied it to various objects, such as carpets, blankets, a cloak, the rainbow, blood, a cloud, the sea and the wave.

Xenophanes uses the same word in describing the third and cold colour in the rainbow as seen by him. Aristotle names three colours, red, green and violet.

Also in several old paintings colour-blind mistakes are often seen.

Mr. F. W. Edrige-Green, in *The Nineteenth Century and after*, April 1902, discussing these facts, gives his opinion that men were originally colour-blind, and that the sense of colour is a gradual and recent development, first as to the perception of the difference between red and violet, then green, then yellow, then blue, then orange, and lastly indigo.

It is commonly supposed that a bull can discern red, for he certainly objects to it. A most interesting and important series of experiments have been recently made by Dr. Nuttall and Mr. Shipley in trying to discover some means by which mosquitoes might be warded off, as it is known that they often carry about with them the germs of malaria and various

dangerous fevers, and infect people by biting them.

They made their experiments in England. Seventeen open boxes painted different colours were placed near the studio and supplied with fresh bananas to attract the insects. The number of mosquitoes (*Culex anopheles*) which entered the boxes were counted daily. At the end of seventeen days the figures were added up with the following results, showing the preference of mosquitoes for the various colours. The number of insects is given opposite the colour of each box.

Navy-blue box . . .	108
Dark-red ,, . . .	90
Dark-brown ,, . . .	81
Scarlet ,, . . .	59
Black ,, . . .	49
Slate-grey ,, . . .	31
Olive-green ,, . . .	24
Violet ,, . . .	18
Green ,, . . .	17
Blue ,, . . .	14
Light-grey ,, . . .	9
Light-green ,, . . .	4
Sky-blue ,, . . .	3
White ,, . . .	2
Yellow ochre ,, . . .	2
Light-yellow or khaki ...	none.

The adoption of a khaki costume would appear from this investigation to be the safest colour to

wear in countries infested by mosquitoes, which certainly seem to have a keen sense of colour, and very definite tastes with regard to it.

We consider next our perception of form or the shape of things by vision. Much discussion has arisen as to our perception of form.

A theory was put forward by the celebrated Bishop Berkeley that our whole notions as to the size and solidity of all external objects were due not to vision, but to ideas originally derived from the sense of touch, and which were attributed to sight, because certain sensations of touch were uniformly associated with certain perceptions of colour, which, he said, was all the eye could see. He also maintained that we could not derive our knowledge of distance from sight, because every ray of light which reached the eye from any object, whether it were near or distant, was like a line viewed end-on, and, therefore, only discernible as a point.

Let me explain his reasoning by some familiar illustrations. When a baby begins to show the first signs of perception it is attracted by the light of the lamp standing on a table. Its little hand is extended to touch the pretty bright thing, because it has no conception of distance. Experience teaches the child that the lamp is further off than the length of its arm. Babies have been known to make a grasping motion with the hand towards the moon when they saw it shining in the sky. Later on the child learns by sundry knocks and hurts that objects are nearer than he thought they were. He suffered

no injury when he stretched out his arm towards the moon, but a very different sensation greeted him when he rapidly extended his arm towards the corner of a table. So Bishop Berkeley traced our knowledge of distance to experience gathered slowly by means of the sense of touch. In the same manner he accounted for our knowledge of the shape of things. A certain appearance was associated with touching and feeling the object, and when we saw similar appearances we concluded by our judgment that they, if touched, would be found to have a similar shape.

If all men had been created with only one eye each, there might have been much more force in this reasoning, especially in his argument about each ray of light being viewed end-on, and thus manifesting itself only in a point.

We know that persons who are blind in one eye cannot judge distances nearly so well as those who have two eyes. We can make ourselves one-eyed by closing one eye, and when we have done so, let us place a sixpence on a table and then try to hold our forefinger exactly six inches above it. We can do so with the utmost ease when we keep both eyes open, but it is a feat of considerable difficulty when one eye is shut.

This experiment shows that our knowledge of distance is in some way connected directly with the fact that we possess two eyes.

Bishop Berkeley was born in 1624, but it was not until the year 1838, when Professor Wheatstone pub-

lished a paper in the *Philosophical Transactions* for that year, that attention was drawn to the importance of the sight of both eyes in giving us reliable information as to the shape and solidity of external objects independent of information derived from the sense of touch.

The facts to which he referred were these. As our eyes are some distance apart, when we look at an object it is evident that the figure does not pre-

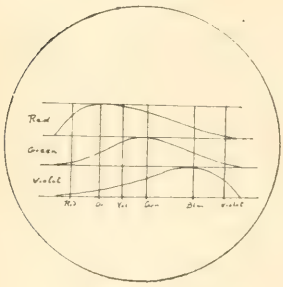

FIG. 67.

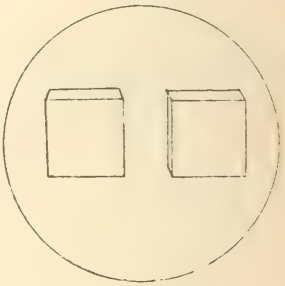

FIG. 68.

sent exactly the same shape to one eye that it does to the other. If, for instance, a cube is placed at a moderate distance exactly opposite to one eye so that only the front is seen, when we open the other eye we see not only the front, but a little of one side as well (Fig. 68).

Also, if we stretch out our arm and hold up one finger between us and an object, such as the knob of a door-handle, so as not to hide it, if we look at the knob it appears placed between two fingers, and if

we change and look at our finger we see two knobs, one on each side of our finger. This is the parallax of vision, and it is the cause why a view of objects, such as furniture in a room, differs so much from any picture of the furnished room which can be drawn on a flat surface such as a sheet of paper. In looking at things we see at once the space which separates them in distance, whereas in a flat picture we must depend on lines of perspective to indicate the same effect.

Wheatstone conceived the idea of making two pictures of objects, each picture to be what would be seen by one eye, and therefore differing slightly from one another. In those days photography was not invented, so the objects drawn were figures such as cubes. He placed these pictures endwise to the spectator, and between them he placed two mirrors which reflected them and caused the two pictures to be seen as one (Fig. 69). The mirrors are marked M and the pictures P. He called his instrument a stereoscope, from two Greek words—"stereos," solid, and "skopein," to see. The stereoscope has since become a familiar instrument, affording both recreation and instruction. In 1849 Sir David Brewster improved it so as to show two pictures placed side by side as one picture, in which the space dividing the figures could be clearly seen, and they seemed to stand out one from another as when looked at in nature. Photographs made for the stereoscope are taken on two plates simultaneously, the lenses of the camera being placed at the same distance from

one another as the human eyes are apart from one another. By exaggerating the distance between the eyes of the cameras, photographers obtain very striking effects, which, nevertheless, are not true to nature. We conclude, therefore, that our chief means by which we discern the relative distance of objects is by the use of our two eyes.

At the same time judgment acquired by experience from touch or otherwise has a great deal of influence in determining what we think we see. We are accustomed to look straight before us, and to take our measurements by sight a short distance from the ground. Amateur sportsmen know that it is much easier to hit a running rabbit or a rising partridge than to hit a pheasant flying overhead. The reason is that we are not accustomed to take measurements of distance by sight when looking up towards the sky. When we see the moon rising above the fields she seems to be much larger than when we see her in the clear sky overhead. But if we were to measure her by an instrument we should find that her disk subtends the same angle—that is, it is really the same size in whatever part of the sky she is seen.

One change in her shape is due not to judgment, but to reality. When very near the horizon, the full moon does not look round, she is broader across than from top to bottom; but this is because of the refraction caused by the atmosphere, which lifts up the lower half somewhat more than the upper half, as the rays of light from the lower half have to

reach us through denser air than those from the top.

If we want to dissociate our eye from the influence of judgment, we have only to place it in a position to which we are not accustomed. Amateur artists, for instance, look at a distant mountain which they know is high. They draw according to what they think rather than according to what they see. They complain that photographs diminish the height of mountains and make them look insignificant, therefore they proceed to improve on what the camera reveals as to the apparent height of the mountain. But if they were to stoop down so as to look at the mountain under their arm, the eye, being deprived of its prejudice of judgment, would see the mountain to be exactly the height shown in the camera. I speak of the camera rather than of the photographic print, because the picture in the camera gives the true colour by which aërial perspective is seen, whereas in the print, being usually a uniform brown, the aërial perspective is lost, and the mountain is coloured as if near, and looks consequently too low.

An artist looks at a field on a distant hill. He knows that the field is green, and he is tempted to paint it according to the verdict of his judgment, but if he look at it with his head bent sideways, he sees how far its green colour is modified by the misty blue of the atmosphere. The art of painting is to produce an illusion. This is done by placing on a flat surface the true colours due to aërial perspective. If these be given the judgment of the

person who looks at the picture deceives him; when he sees the true colour he thinks that he sees the distance.

Another art in producing the illusion of painting is by remembering that when we look at nature we see the object on which we concentrate our attention with great distinctness; we see the other surrounding objects, such as the background, but not at all with the same force as that with which we see the principal object.

The art of the painter is to know the relative values of these impressions, and to compel the spectator to see the chief figures distinctly by reducing the values of the tints in the subordinate parts of the picture. Thus the judgment of the spectator is helped to complete the illusion.

There are occasions when what we see overpowers the judgment. When we dip a stick into a basin of water it appears to be bent. This, as we have seen, is caused by the laws of refraction. But no matter how we persuade ourselves that we know the stick is straight, if we take it out of the water and feel it a dozen times so as to be sure that it is straight, the moment we replace it in the water it looks to be bent.

There is a certain defect in the eye which is so slight that we are rarely conscious of it. We have seen that a ray of light when dispersed into its component parts consists of various colours from red to violet. We saw also that the violet rays, when passing through a prism, bend further from a right

line than the red. They must, therefore, do so when they pass through the crystalline lens of the eye and converge towards a focus (Fig. 70). Here we see a red ray and a violet ray in the process of being focused. The violet ray, bending more than the red ray, reaches the straight line somewhat nearer to the lens than the red ray. We cannot, therefore, focus them together. The difference is so slight that we do not perceive any prismatic colours when

Fig. 69.

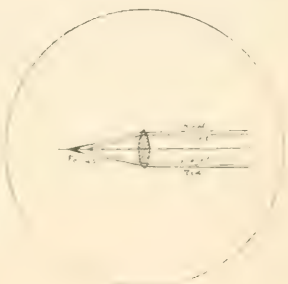

Fig. 70.

looking at ordinary objects, but if we looked at a red light and a violet light which were close together and at a very long distance from us we could see each separately, but not both together. We would unconsciously focus one or the other, and thus see them in rapid succession. If we look through a lens in which this tendency to form prismatic colours has not been rectified by making it of two sorts of glass, crown-glass and flint-glass, which have different powers of refraction, we do see the prismatic colours so much that the defective telescope is of little use.

Still we must admit that the want of provision for entirely getting rid of these prismatic colours is a defect in the eye, when regarded as an optical instrument. Another fact has been counted as a defect, but it has such important compensations that I cannot admit it to be a defect. I allude to the fact that if the eye were the only photographic camera, instantaneous photography would be impossible. When light strikes the retina it makes an impression which lasts for some time after the light has ceased. Also, unless the light has certain time to continue playing on the retina it makes no impression of distinct vision. I might give many illustrations of this fact. If we put a thin stick into the fire until the point is glowing hot, and then whirl it round, we do not see it as a point of light, but as a glowing, luminous circle ; whereas if a cinematograph series of photographs of it were taken, we should see on them a circle of dots of light. When we look at a horse galloping, his legs move so fast that we cannot see them. No person knew how his legs moved until instantaneous photography revealed the motions made in the thousandth part of a second. Also when a carriage-wheel is rotating rapidly we cannot see the spokes, although the photograph records the position of each of the thin wire spokes of a racing bicycle.

So far these facts seem to indicate a defect in vision, but the compensations are many. When we blink our eyes, owing to the retention of the image formed on the retina, we are not conscious of the in-

terruption of recurring moments of darkness. We see continuously, just as if we did not blink. But another compensation is more important. Were it not for this retention of vision we could only see one letter of each word at a time when we are reading. But as the eye runs rapidly along the line of print, the impression of the letters remains until we have seen the whole word, or even words, and thus we are enabled to take in the meaning of the sentence with ease. The photographic camera has another curious advantage over the eye. It can gaze for hours at one spot without fatigue, and thus it gathers in the course of hours the faint light of distant stars and records their images on a plate, so that we know of thousands of stars by photography which the eye of man has never seen, because when we gaze at one spot, or look at one colour for any length of time, our eyes become so fatigued that they cannot see. This fatigue is specially noticeable in the case of looking at colour. If we gaze for only thirty seconds at a word printed red, and then look at the ceiling, we see the word coming out in blue-green; or if the word be printed in blue, we see it reproduced on the ceiling in yellow. This is because the eye gazing at the colour becomes so fatigued that it cannot perceive any longer the rays of that colour in common light, and therefore it sees only the complementary colour. Take red from the whole ray of light, and you have green; take blue, and you have yellow. We see, therefore, when fatigued, only the colours by which we have not been fatigued. I give another

instance. When daylight is waning, the servant brings a lamp into the room. As soon as it is brought in the shadows of the furniture seem to be blue. The reason is that, being dazzled by the abundance of yellow rays proceeding from the lamp, we cannot see the faint yellow rays in the waning daylight, and these yellow rays being eliminated practically, the remainder seems blue. When the daylight goes, all the rays go, and then the shadows

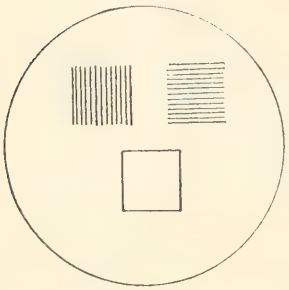

FIG. 71.

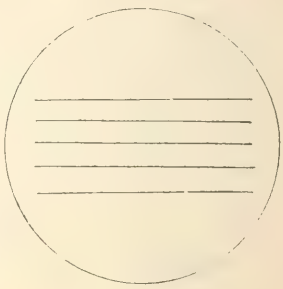

FIG. 72.

caused by the lamplight resume their natural hue of black.

These are some instances showing how our eyes can deceive us in looking at colours, but, though it may surprise us, our eyes can also deceive us in looking at form. Let us try an experiment (Fig. 71). Here we have three spaces exactly the same size, but by drawing lines up and down the first it looks broader, and by drawing them across the second it looks higher, while the third appears

to be smaller than either of the other two. Again, let us look at some parallel lines (Fig. 72). We see that they are parallel. But if we cross them with sloping lines our vision is so perplexed that they look crooked in various directions (Fig. 73).

Can we say after this experience that "seeing is believing"? And yet we must surely confess that of all avenues by which knowledge comes to the mind of man, sight, which conveys to us the marvels

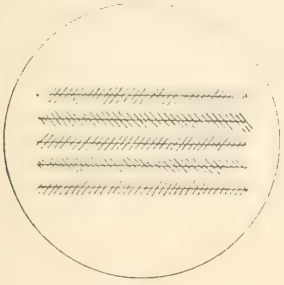

Fig. 73.

of the world of light, is the grandest and the most sublime.

In considering the subject of light we have confined ourselves to that part which concerns vision. We have treated of the colours of the spectrum, including the ultra violet rays which can be rendered visible by fluorescence, but we have said nothing about the ultra red rays, which belong to the other end of the spectrum. These are not seen, but they are felt in the form of heat.

That heat is caused by vibrations or waves ana-

logous to those which form visible light can be proved by the fact that they can be tested and treated in the same way. They are reflected and refracted. They can be brought to a focus by a lens, and show their activity by setting on fire any combustible substance placed in that focus. The rays of light emanating from the sun are not nearly so numerous as the rays of heat which pour forth in all directions. So much we say lest it should be thought that the heat-waves as an integral part of light had been forgotten. But to treat of them adequately would require a separate book.

When we think of the marvel and the intricacy of these facts which we have considered as only a part of the vast field of nature, the thought occurs spontaneously, "All Thy works praise Thee, O Lord; they show the glory of Thy kingdom and talk of Thy power."

APPENDIX

To prepare slides for a magic lantern as illustrations thrown on a screen while the reading is being given, proceed as follows :—

I. By Drawing.

Procure pieces of thin glass, free from flaws, and cut to the exact size of $3\frac{1}{4}$ inches square. Two pieces are required for each slide. Good glass for the purpose may be had by soaking old quarter-plate negatives in hot water, cleaning them, and cutting off a strip with a glazier's diamond so as to make them $3\frac{1}{4}$ inches square.

Draw with a compass on paper a circle $2\frac{3}{4}$ inches diameter, and inside this copy the illustration suitably enlarged. Place the glass over the drawing and trace it with a steel crow-quill pen, using Indian ink. Then hold the outline thus made at a convenient angle over white paper in good light, so as to see it clearly, and touch in the details with the pen. Then take an opaque mask (which can be purchased from any optician) the size of the space

between the square and the circle, and with seccotine or good gum lightly applied to the white side of the mask, place it on the glass on the same side as the drawing, and see that it is evenly laid. Then take the second piece of glass (quite clean), and apply a thin rim of seccotine round the edge of one surface, and place it over the drawing, pressing the two glasses gently but firmly together. A neat finish may be made by gumming a narrow strip of paper round the sharp edges of the glass. Fix a small white label in the corner, showing the number of the plate clearly written. The slide is then ready for use.

II. By Photography.

Place the picture in a good diffused light, and photograph it on an ordinary quarter-plate at close focus, well stopped down so as to secure clear definition.

Take care that the picture is exactly central and parallel with the plate in the camera. Develop in the ordinary way.

When dry, place the negative in a printing-frame, and place over it, film to film, one of *Paget prize plates, lantern slow*. Do this in a red light. Then hold the printing-frame about two feet from an ordinary gas-jet, or duplex petroleum lamp, without a shade, for about thirty seconds. Develop in the ordinary way, and the result is a lantern slide.

Fix a mask suitable to the size of the photograph, and finish as directed above.

Should it be found impossible to procure a magic lantern, diagrams drawn on large sheets of paper with charcoal instead of a pen will be found to answer the purpose of instructive illustration.

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